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PROCEEDINGS OF NATIONAL SYMPOSIUM ON FOOD PROCESSING WASTES (1ST), HELD IN PORTLAND, OREGON ON 6-8 APRIL 1970

Pcific Northwest Water Laboratory
Corvallis, Oregon

1970

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WATER POLLUTION CONTROL RESEARCH SERIES • 12060---04/70

PROCEEDINGS

FIRST
NATIONAL SYMPOSIUM ON FOOD PROCESSING WASTES

APRIL 6-8, 1970 PORTLAND, OREGON

SPONSORED BY:
FWQA Pacific Northwest Water Laboratory
USDA Western Regional Research Laboratory
National Canners Association
Northwest Food Processors Association

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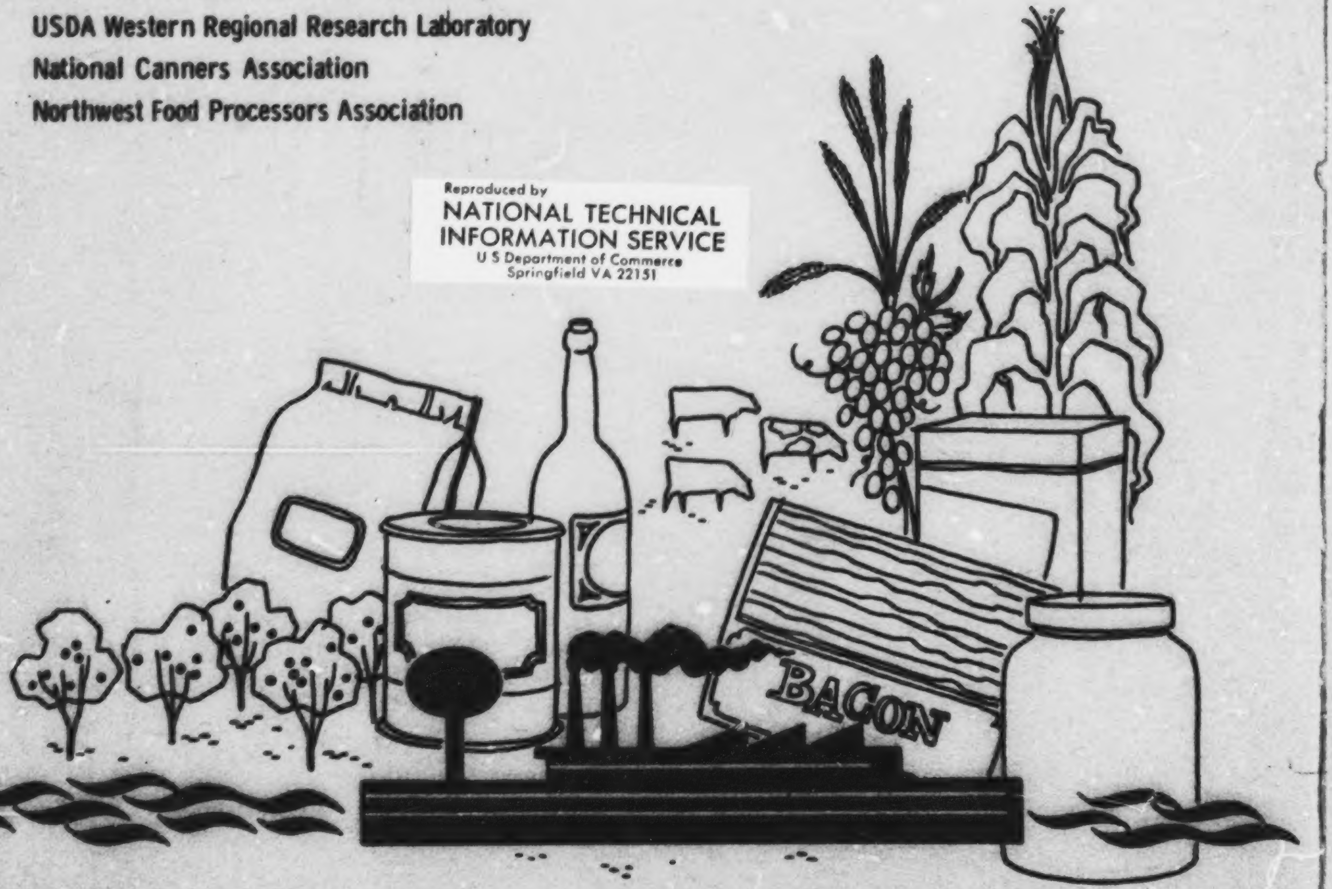

S. DEPARTMENT OF THE INTERIOR • FEDERAL WATER QUALITY ADMINISTRATION

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WATER POLLUTION CONTROL RESEARCH SERIES

The Water Pollution Control Research Reports describe the results and progress in the control and abatement of pollution in our Nation's waters. They provide a central source of information on the research, development, and demonstration activities in the Federal Water Quality Administration, in the U. S. Department of the Interior, through inhouse research and grants and contracts with Federal, State, and local agencies, research institutions, and industrial organizations.

Inquiries pertaining to Water Pollution Control Research Reports should be directed to the Head, Project Reports System, Planning and Resources Office, Office of Research and Development, Department of the Interior, Federal Water Quality Administration, Room 1108, Washington, D. C. 20242.

First National Symposium on Food Processing Wastes
Proceedings

Sponsored by:

Pacific Northwest Water Laboratory
Western Regional Research Laboratory
National Canners Association
Northwest Food Processors Association

April 6-8, 1970
Portland, Oregon

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FWQA Review Notice

This report has been reviewed by the Federal Water Quality Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Quality Administration, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWARD

This was the first of a planned series of conferences to discuss current research on treatment of food processing wastes. This Symposium was co-sponsored by Pacific Northwest Water Laboratory of the Federal Water Quality Administration, the Western Regional Research Laboratory of the U. S. Department of Agriculture, National Canners Association, and Northwest Food Processors Association.

The first two days of the conference were devoted to an in-depth review of current research and demonstration projects which have been funded largely by the Federal Water Quality Administration. The third day was concerned with discussions of research on improved in-plant and in-field processing intended to reduce the quantities of waste needing treatment, and replaced the Annual Western Regional Research Laboratory's Collaborators Conference.

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SYMPOSIUM OBJECTIVES

by

James R. Boydston*

This meeting beginning today marks a milestone, I think, in the national program of research and development of water pollution control methods for the food processing industry. The program will, I hope, be the first of a continuing series of symposia to make current information available in an open forum meeting of this type and to give you an opportunity to question those experts who are actively developing or demonstrating new or improved treatment methods.

During, or following the course of this meeting, I would like to have comments from you individually as to your opinion on how often meetings of this type might be held and still be of value. Also, we would like suggestions on other possible locations for future meetings.

This meeting marks a further milestone in that it truly represents a cooperative, coordinated program between industry and government, to mutually solve troublesome water pollution problems. This cooperation is demonstrated by the sponsorship of this meeting. In addition to the Federal Water Quality Administration, the Government is represented by the Western Regional Research Laboratory of the U. S. Department of Agriculture, through Dr. Peter Clark; and industry co-sponsors, the National Canners Association by Mr. Walter Mercer, and the Northwest Food Processors Association through David Pahl; the Technical Program Coordinators are Kenneth A. Dostal, Pacific Northwest Water Laboratory, and Dr. Clark, Western Regional Research Laboratory.

It is timely that a meeting such as this be held to review some of the latest efforts to reduce water pollution from the food processing industry. We are all aware of the current public clamor for a cleaner environment. Those of us who have been working in the field for a number of years and who have been preaching the gospel of water pollution control are somewhat surprised at the magnitude of the current tidal wave of public support for water pollution control. Perhaps one of our new roles as professionals in the field is to direct these energies into channels where they will truly accomplish desirable ends. We must avoid being stampeded into a wave of new plant construction unless we give careful consideration to the effluent requirements to be met, the economics of various treatment methods, and the possibilities of by-product recovery.

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The cause of this justifiable national concern has now become obvious to us all. Our world population has already exceeded the optimum level that can be supported by our finite quantities of natural resources. Medical science can reduce death rates through prevention and control of disease, scientific farming methods can increase the world's food supply through more efficient growing methods, and our modern technology can transport men to the moon and back, but we can do nothing to increase the available quantity of water on this earth. We must, therefore, do more and more to improve the quality of the used water we return to our streams and lakes.

As population and demands for water increase, it is obvious that sooner or later most industries will be faced with requirements for tertiary treatment. As a result, direct water re-use will become commonplace.

What does all this mean to you as industry representatives? It means you will be faced with ever higher treatment requirements and larger expenditures of funds for construction and operation of treatment facilities. If you listened to the President's Message to Congress on the environment in February of this year, you heard him say in his 37 point program that he was asking Congress for "extension of Federal-State water quality standards to include precise effluent standards for all industrial and municipal sources". I don't doubt that Congress will pass the necessary legislation to accomplish the President's goals. If effluent standards are imposed on industry, I think a word of caution is in order. It will be easy to be lured into a trap thinking that an effluent standard set for a particular industrial plant is the final word and that this requirement will be in effect for all time. Obviously, with our accelerating population and industrial growth, competition for water will require that higher effluent standards be imposed and additional plant construction required, often before the original treatment plant is broken in. We must remember that standards that are set for a particular stream are based upon the assimilative capacity of the stream and some given set of waste loadings, usually the existing waste sources with some added allowances for future growth. However, when additional population and industrial growth occur without a corresponding increase in the capacity of the stream to absorb the wastes, either processing methods must be revised, additional treatment must be installed, or plant production capacities limited.

The President also said that industry must recognize that waste treatment is a cost of doing business. This statement implies that there will not be any construction grants program for industry.

Let's consider for a moment where we stand today regarding food processing waste treatment. Basically, wastes from your industry are not difficult to treat. Some segments of the industry have some specialized wastes with difficult treatment problems such as BOD concentrations in excess of 40,000 mg/ℓ but most of the wastes can be treated by conventional means. Many of the papers you will hear during this conference will concern conventional, secondary treatment processes. I am not convinced that a great deal more work needs to be done on secondary treatment of food processing wastes. We may spend some additional effort on increasing the efficiency of secondary plants or decreasing the construction or operating costs, but in most cases we can now define a practical method of secondary treatment.

Our research goals should include the refinement of conventional methods of treatment; the development of processes capable of higher degrees of treatment or completely closed loop systems where the treated effluent is reused within the processing plant; efforts should be expanded on processing methods to reduce the quantity of water required per ton of product; and, finally to develop profitable byproducts from the wastes resulting from current processing methods.

The role of FWQA in this research effort, as I see it, is more one of coordinating and guiding a national research effort than it is to embark on a large scale in-house research program. Our in-house activities will be geared toward providing technical assistance to you in industry on waste treatment problems and to demonstrate new techniques for treating these wastes. Of the Federal research dollar, about 10 percent is currently expended on in-house research, and 90 percent of the Federal funds available are spent on research and demonstration grants and contracts to industry, universities, and consultants for the development of new treatment methods. (My colleagues suggest that I refer to this as extramural research rather than out-house activity.) The current level of Federal expenditures for this fiscal year in the food processing area is about $3 million, including joint treatment, but we expect this will decrease in the future.

I see a further major role for FWQA in publishing reports on waste treatment research and sponsoring additional conferences of this type to enable you to learn of new developments as early as possible so that you may benefit from current research in this area of water pollution control. We recognize that there can be considerable delay in preparing, publishing, and distributing research reports, and it is our hope that by conferences like this some of the time delay can be avoided. In other areas of data dissemination, FWQA headquarters regularly publishes a summary listing of projects of the Industrial Pollution Control Branch and the Corvallis Laboratory is now starting to publish a regular (quarterly) review of the in-house and grant projects.

The Western Regional Research Lab has a continuing program to develop better methods of food processing and is directly concerned with methods which reduce water use. Some industry associations have not only conducted valuable research of their own, but have been most active in providing timely information on research developments from all sources to their members.

In closing, let me say that we are faced with some serious challenges: we have a deteriorating environment and an aroused public. We know a few of the answers and a lot of the problems. But, I think that cooperation such as shown here today between industry and Government can make the food processing industry a leader in the fight for clean water.

FEDERAL WATER QUALITY ADMINISTRATION
RESEARCH, DEVELOPMENT AND DEMONSTRATION PROGRAM

by

William J. Lacy and Harold G. Keeler*

Recently, President Nixon signed into law a bill to "maintain conditions under which man and nature can exist in productive harmony".

Americans today are reacting to the environmental chaos they see around them. And they are speaking out about foul air. And polluted waters. And clogged highways. And wasted resources. In general, the public is convinced--as we all should be--that the technological genius that has provided abundance and even conquered space ought to be able to do these things without polluting the environment on which we all depend.

The 1970's must be the decade when we pay our debt to the part by reclaiming the purity of our environment. It is literally now or never. Commissioner David D. Dominick recently remarked, "The threats, both present and future, to the environment are obvious. Our responsibilities are equally clear. I am convinced that local, State and Federal water pollution control programs--with industry's cooperation--can and will clean up our water.

"If these programs are effectively meshed, coordinated and directed, the American water clean-up drive will begin to produce substantial results in the next five to ten years and clean, usable water will be assured for tomorrow."

The name of this program is unusual--perhaps unique in Government. We have a Research, Development, and Demonstration Program--a coordinated, problem-solving program which is dedicated to exploratory research of new and imaginative pollution control methods; the engineering development of these methods to solve the practical problems associated with bringing an "idea" out of the laboratory and into the real world; and, finally, the demonstration of this new technology to go that extra, normally forgotten step of showing the decision-makers that new answers, new technology have really arrived and are available for use.

In FWQA, we are carrying out a highly mission-oriented research, development, and demonstration program. Each of our projects should be responding to an identified need for an answer. These "needs" are specified and assigned priority primarily through input from the non-research elements of FWQA. In short, we are trying to respond to the needs of the agency as a whole, not necessarily the litany which the researchers themselves deem important.

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*Respectively, Chief, Industrial Pollution Control Branch; and Manager, Food and Kindred Products; Division of Applied Science and Technology, Research and Development, Federal Water Quality Administration, Washington, D. C. 20242.

There are really only two major categories of "answers" we are seeking. First, how do we define the water quality goals to be attained? Second, how do we reach these goals at least cost? With regard to quality goals, research is required on the effects of pollution. What are they? How is the degree of effect related to the amount of pollution? And, how can we predict the level and type of effect in advance? With this type of information we can improve and extend the water quality standards now being established and implemented for the Nation's waters. Simply knowing what water quality is required is not enough, of course. We need to develop new and improved means for control of pollution in order to reduce the cost of pollution abatement to the very minimum possible in those cases where we already have some ability to control, but beyond this, our quest is to develop and demonstrate means for controlling that pollution which today is literally uncontrollable or untreatable at any cost! Corollary to and, in fact, inseparable from this objective is the simultaneous upgrading of wastewater quality such that used water may be reused again--a concept of major significance in extending our relatively dwindling fresh water supply.

To assist in managing our program and in setting priorities and resource allocations, a problem-oriented project categorization is utilized (see Table 1). Eight major categories exist, the first five relate to single-source-related pollution problems from municipal, industrial, agricultural, mining, and from "other" sources. The last three categories relate to problems of a multiple-source nature, i.e., where the answers will be applicable broadly to many different sources of pollution. In the single-source category, we are working on such pollution problems as combined sewer discharges, pulp and paper mill wastes, agricultural runoff, acid mine drainage, petrochemical wastes, and oil pollution. In the multi-source categories, we have programs on eutrophication, thermal pollution, removal of nutrients and refractory organics, and effects of pollutants on fish and aquatic life.

The mechanisms utilized in carrying out this program are threefold:

1) In-house research and development at seven laboratory locations plus a number of associated field sites.

2) Contract projects, primarily with industry.

3) Grant projects with universities, industries, States, and municipalities.

Contract projects are funded entirely with Federal dollars and are utilized primarily for problem analysis, laboratory investigations, or pilot-scale research projects which involve a high degree of uncertainty and which are primarily aimed at determination of feasibility and

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RESEARCH, DEVELOPMENT AND DEMONSTRATION PROGRAM

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Table 1. Research, Development and Demonstration Program

development of design requirements. These are not the types of projects that municipalities and private corporations will often sponsor or co-sponsor with their own funds due to the large degree of risk involved. The work performed under contracts often requires highly specialized personnel and equipment and facilities having a high value over a short period of time, but limited value in the long-term.

Notable examples of contract projects pertaining to the petroleum-petrochemical industry include: (1) a five-year cost projection of pollution control facilities required by specific chemical industries, (2) a state-of-the-art report concerning petrochemical wastes to serve as a basis for future program planning, and (3) a presentation of the many components which constitute a preliminary wastewater treatability study with specific reference to petrochemical and refinery wastewaters.

Grant projects require some level of matching support from the grantee. Grants are employed in meeting objectives where it is desirable to utilize State, municipal, academic, or industrial talents and expertise in carrying out research, development, or demonstration efforts on a cost-sharing basis resulting in mutual benefit to both the Federal Government and the grantee. Demonstration projects are particularly significant in that they permit us to carry research and development findings on into the full-scale phase, thereby showing what can be accomplished through use of new technology and at what cost.

Industry's pollution problems are diverse as its products (see Table 2). From food processing to power plants, from oil refineries to coal mines, the pollution problems vary greatly. Some industrial wastes are organic and lend themselves to the same biological treatment long used for municipal sewage; others are inorganic, requiring chemical or physical treatment.

Frequently, organic wastes from food processing and pulp and paper mill industries can be treated by biological processes. In other cases, such as wastes from metal finishing, chemical, petroleum, and steel industries, different treatment methods are necessary (see Table 3). In short, each industry group has its particular circumstances which require its own technical and economic solutions.

Today's industrial water pollution problems are magnified by the older plants and factories many of which are marginal enterprises and tend to retard our efforts.

Dr. David G. Stephan, the Assistant Commissioner for Research and Development, recently stated, "Our long-range objective in the FWQA research program is to provide the necessary treatment systems for attaining any degree of wastewater purification which may be required at the minimum feasible cost." The word "systems" was used in this objective. Rarely will any advanced waste treatment process be used as the sole technique in the purification of wastewater for reuse. Generally, systems of selected unit processes in series or in parallel will be required to

Table 2. Standard Industrial Classification of Industries of Significance for Water Pollution

CODE	
	FOOD AND KINDRED PRODUCTS
201	Meat products
2011	Meat slaughtering plants
2013	Meat processing plants
2015	Poultry dressing plants
202	Dairies
2021	Creamery butter
2022	Natural and process cheese
2023	Condensed and evaporated milk
2026	Fluid milk
203	Canned and frozen foods
2033	Canned fruits and vegetables
2034	Dehydrated foods products
2035	Pickles, sauces, salad dressings
2037	Frozen fruits and vegetables
204	Grain mills
2041	Flour mills
2043	Cereal preparations
2046	Wet corn milling
205	Bakery products
206	Sugar
207	Candy and related products
208	Beverages
2082	Malt liquors
2084	Wines and brandy
2085	Distilled liquor
2086	Soft drinks
209	Miscellaneous foods and kindred products
2091	Cottonseed oil mills
2092	Soybean oil mills
2094	Animal and marine fats and oils
2096	Shortening and cooking oils

Table 2. Standard Industrial Classification of Industries of Significance for Water Pollution (continued)

CODE	
	TEXTILE MILL PRODUCTS
2211	Weaving mills, cotton
2221	Weaving mills, synthetic
2231	Weaving, finishing mills, wool
225	Knitting mills
226	Textile finishing, except wool
228	Yarn and thread mills
229	Miscellaneous textile goods
24	LUMBER AND WOOD PRODUCTS
242	Sawmills and planing mills
2421	Sawmills and planing mills
26	PAPER AND ALLIED PRODUCTS
2611	Pulp mills
2621	Paper mills, except building
2631	Paperboard mills
264	Paper and paperboard products
265	Paperboard containers and boxes
2661	Building paper and board mills
28	CHEMICALS AND ALLIED PRODUCTS
281	Basic chemicals
2812	Alkalies and chlorine
2818	Organic chemicals, n.e.c.
2819	Inorganic chemicals, n.e.c.
282	Fibers, plastics, rubbers
2821	Plastics materials & resins
2823	Cellulosic man-made fibers
2824	Organic fibers, noncellulosic
283	Drugs
284	Cleaning and toilet goods
2851	Paints and allied products
2861	Gum and wood chemicals
287	Agricultural chemicals
289	Miscellaneous chemical products
29	PETROLEUM AND COAL PRODUCTS
2911	Petroleum refining
295	Paving and roofing materials

Table 2. Standard Industrial Classification of Industries of Significance for Water Pollution (continued)

CODE	
30	RUBBER AND PLASTICS PRODUCTS, n.e.c.
3069	Rubber products, n.e.c.
3079	Plastics products, n.e.c.
31	LEATHER AND LEATHER PRODUCTS
3111	Leather tanning and finishing
32	STONE, CLAY, AND GLASS PRODUCTS
3211	Flat glass
3341	Cement, hydraulic
325	Structural clay products
326	Pottery and related products
327	Concrete and plaster products
3281	Cut stone and stone products
329	Nonmetallic mineral products
33	PRIMARY METAL INDUSTRIES
331	Steel rolling and finishing
332	Iron and steel foundries
333	Primary nonferrous metal
3341	Secondary nonferrous metals

Table 3. Industrial Source versus Significant Constituent Pollution

Sector	Constituent						
	BOD	SS	TDS	Acid	Heavy Metals	Oil	Btu
Metal and metal products		X	X	X	X	X	
Chemicals and allied products	X	X					
Power production							X
Paper and allied products	X	X					
Petroleum and coal products	X		X			X	
Food and kindred products	X	X	X				
Machinery and transportation equipment	X	X	X		X		
Stone, clay and glass products		X	X				
Textile mill products	X	X					
Lumber and wood products	X	X	X				
Rubber and plastic	X	X					

meet the various reuse criteria. Included will be one or more processes to provide for the permanent non-pollutional disposal of the inevitable sludges and blow-down streams generated by the separation process used.

From the systems and model formulation viewpoint, the industrial pollution research priorities area is the critical place to start. Industrial pollution as a class accounts for the largest share of the Nation's water pollution problem. For example, the industrial wastewater volume is 2.5 times that of the sewered population; the "five-day" BOD of industry is 3 times; and the suspended solids over twice that of the sewered population. Further, given the highly correlated co-location of major polluting industry groups with population, industrial water pollution has a greater impact on the population than would be expected. In addition, to further complicate the industrial pollution problem, in recent years while the major polluting industries have grown essentially at triple the rate of population growth, it appears that in many areas the proportion of untreated industrial waste has been growing even more rapidly. In any event, the magnitude of the problem whether based on Industry Profiles estimates or Census-Municipal projections, is measured in dollar terms ranging from one to two billion dollars a year in annual outlays in the early 1970's.

If the primary job of FWQA is to get all water pollution sources to install at least a secondary level of treatment, then the long-term task would be how to handle the sludge disposal problems.

That wastewater renovation and water reuse are technically feasible is assured at this point. The major challenge ahead relates to evaluation and development of alternative separation and disposal processes which show promise of improved performance at reduced costs.

Renovated wastewater for reuse would alleviate simultaneously two of our Nation's major water resource problems--water pollution and water supply.

This sounds great, but what will this solution cost? Yes, cost--now, today. The average cost of water delivered to your sink, bathroom, kitchen, lawn, etc. is less than \$.08/ton. Milk costs about \$290/ton delivered to your door; and even the cheapest soil costs \$3/ton dumped on your lawn and topsoil costs \$25/ton.

Our in-house activity forms the foundation for an effective over-all program. Our in-house researchers must establish objectives and plans of attack; they must review and evaluate the many, many project proposals received by this agency; allocate the available funds; and integrate the results of these efforts into usable technology. We believe they must be contributing creative input of their own. In short, we believe a strong in-house program is an essential foundation for an effective grant and contract effort.

The research and development program also involves the assignment of specific areas of technical responsibility to each of our laboratories. Each laboratory functions as a national focal point for research on a given set of problems, and in this way duplication of facilities, staff, and effort among the various laboratories is avoided. These research laboratories are located at Cincinnati, Ohio; Athens, Georgia; Ada, Oklahoma; Corvallis, Oregon; College, Alaska; Duluth, Minnesota; West Kingston, Rhode Island; and Edison, New Jersey.

Laboratory research assignments deal with the experimental application of technology for treatment, control, or prevention of pollution from single-source contributors. Three laboratories have "Treatment and Control Research" assignments related to the Food and Kindred Products industry: Robert S. Kerr Water Research Center, at Ada; Southeast Water Laboratory, at Athens; and Pacific Northwest Water Laboratory, at Corvallis.

All FWQA laboratories have certain research assignments from which research findings emerge that have potential application to wastes from the food and kindred products area. The breakdown of the industries of significance for water pollution research programs and the waste generation coefficients in pounds BOD/employee are shown on Table 4. All the laboratories are involved with the development of water quality criteria. Primary effort at these laboratories is centered on developing quality requirements necessary for propagation of various fish and aquatic life. Special emphasis is now being placed upon temperature and oxygen criteria because they are important to aquatic life and are commonly altered by many types of waste discharges. But attention is also being given to ways of establishing water quality criteria for complex industrial wastes in order to provide improved goals for waste treatment research and plant design and performance.

As to the future, research, development, as well as demonstration efforts will be accelerated in the industrial and agricultural pollution control areas. With specific reference to food processing and canning wastes, a great deal of emphasis will be placed on the development of parameters to measure their pollutional effects, including improved identification techniques. Increased emphasis will be placed on the demonstration of municipal pollution control technology, particularly in joint treatment with industry and nutrient removal. The emphasis in our eutrophication research will be shifting from fundamental research into the demonstration of corrective measures for eutrophication control and lake restoration.

Also to be demonstrated under our future program will be some of the unit operations not particularly common to the food industry, i.e., combined chemical-biological treatment, solvent extraction, ion exchange, electrodialysis, chemical oxidation-reduction, reverse osmosis, freezing, microscreening, airstripping, fluidized bed, and ozonation.

Table 4. Waste Generation Coefficients

(After Bower, RFF)

	Standard Industrial Classification Sector	Pounds BOD/Employee
2011	Meat packing	4596
2026	Fluid milk	1770
2033	Canned fruits and vegetables	16200
2037	Frozen fruits and vegetables	24450
2061	Raw cane sugar	3336
2062	Cane sugar refining	3420
2085	Distilled liquor	3000
2261	Finishing plants, cotton	33200
2262	Finishing plants, synthetic	11580
2621	Paper mills	28960
2631	Paperboard mills	45200
2641	Paper coating and glazing	4260
2654	Sanitary food containers	4500
2911	Petroleum refining	8400
3111	Leather tanning	14700

We anticipate a continual increase in the importance of research on Water Quality Control technology, i.e., the development of non-waste-treatment methods for preventing or controlling pollution. It cannot be overemphasized that a very major program is anticipated in this area as we move into the middle 70's. Unquestionably, thermal pollution will continue to be of growing importance and interest.

In waste treatment and ultimate disposal, major emphasis will be placed on methods of non-pollutional disposal of sludge and concentrates. This is of great importance and one which will receive increasing emphasis. Other areas in waste treatment where increased emphasis can be expected are in dissolved nutrient removal, wastewater renovation and reuse, and in microorganism removal, particularly viruses.

Water quality requirements, i.e., the effects of pollution, will continue to be funded at higher levels. As stated above, this information is essential to the extension and improvement of the Nation's water quality standards. Because of the tremendous number of new compounds being synthesized and finding their way into our environment each year, intensive research investigations must be conducted to develop a predictive capability allowing us to project the potential pollutional impact of these compounds in advance.

The challenge of the 70's is tremendous. This will truly be, as the President said, the "environmental decade." Research must play its role--and research must succeed! The answers we seek are not just "interesting"; they are not just to satisfy intellectual curiosity; they may well be essential to our survival.

Recently, there has been much to-do in all our news media on the sources of pollution and the problems of ecology. I would like to end this with a quote from the comic strip by Walt Kelly regarding who is responsible for our contaminated environment. It was Pogo who said, "We have met the enemy and they are us."

STATUS OF R&D EFFORTS ON FOOD PROCESSING WASTES

by

Kenneth A. Dostal and Robert J. Burm*

Three FWQA laboratories have national research assignments related to the food industry. The Robert S. Kerr Water Research Center in Ada, Oklahoma, is concerned with wastes from meat packing. This effort is being handled under the direction of Mr. Jack Witherow. The Southeast Water Laboratory in Athens, Georgia, has been assigned the citrus and poultry processing areas under the direction of Dr. H. Page Nicholson. The remaining food and kindred product areas are assigned to the Pacific Northwest Water Laboratory in Corvallis, Oregon, within the Waste Treatment Research Program. Mr. Boydston is Chief of this program which also handles the R&D responsibilities for pulp and paper processing.

Although our organization has had rather severe manpower and monetary restrictions since its beginning, the Corvallis Laboratory has participated in some limited field studies. Our first such effort involved the monitoring of a full-scale aerated lagoon which is used to treat wastes primarily from the processing of peas. Copies of a report(1) on this study are available. Figure 1 shows a flow diagram of this facility which was located in Ferndale, Washington. The aerated lagoon with a surface area of 1.75 acres contained about 5.6 million gallons. Each of the four platform-mounted surface aerators at 50 horsepower had a rated capacity of 3,000 pounds of oxygen per day. Effluent from the lagoon flowed through a polishing pond with a volume of 135,000 gallons. During the study period the waste flow averaged about 1 mgd with a BOD load of about 7,000 pounds per day.

In general, the results showed a BOD reduction of 78 percent, from 820 to 180 mg/ℓ. Of the 180 mg/ℓ in the effluent, over 90 percent was associated with the suspended solids. The polishing pond filled very rapidly and since there was no solids removal from it the suspended solids passed straight through. The effluent from the polishing pond contained an average suspended solids concentration of 520 mg/ℓ as compared to 340 mg/ℓ in the feed to the aerated lagoon. With a more positive method of solids removal the system could remove over 90 percent of the BOD.

Another study on secondary treatment of potato processing wastes was conducted jointly by the Potato Processors of Idaho, the Idaho State

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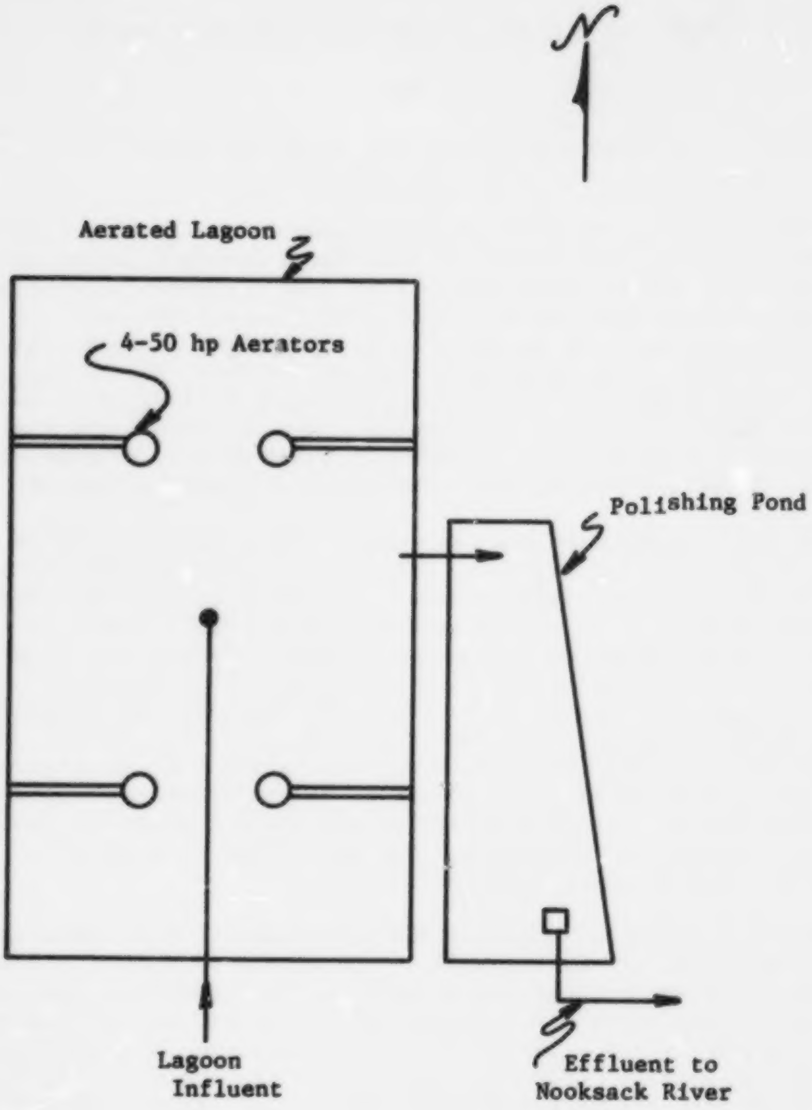
N
Aerated Lagoon
4-50 hp Aerators
Polishing Pond
Lagoon Influent
Effluent to Nooksack River

Figure 1. INDUSTRIAL WASTE TREATMENT FACILITIES
FERNDALE, WASHINGTON

Health Department, and the Corvallis Laboratory. A report(2) on this two-year study has been prepared and distributed.

The objective of this work was the evaluation of anaerobic and aerobic lagoons as potential secondary treatment processes. Three pilot lagoons (Figure 2) were used; each was 40 feet square and about 10 feet deep. The first pond contained a 10 horsepower surface aerator, and was fed primary clarifier effluent at various rates. Anaerobic pond II was covered with three inch thick styrofoam. A pump was used to maintain the solids in suspension. As with pond I, this pond was also fed primary clarifier effluent.

Effluent from pond II was pumped to the third pond which contained a 5 horsepower floating aerator. Various hydraulic loadings were investigated such that the detention time in the first pond was always equal to the sum of the detention times in ponds II and III. Since a wide range in loadings and detention times were investigated, a wide range in results was obtained. It was demonstrated that a BOD reduction of greater than 90 percent could be obtained from either primary clarification plus an aerated lagoon or primary clarification plus anaerobic-aerobic lagoons in series. This was accomplished without pH adjustment or inorganic nutrient addition even though the processing plant used lye peeling of the potatoes. These results were instrumental, at least in part, for the design of two full-scale secondary treatment systems.

Last fall two pilot plants were operated at a cannery in Salem, Oregon. A tank 25 feet in diameter and 10 feet deep containing a 1 horsepower floating surface aerator was used as one pilot plant. The tank contained a device called a tube settler which is a system for high-rate removal of suspended solids. The objective of this study was to see if the tank could be used as both an aeration tank and an aerobic digestor, thereby eliminating the need for separate sludge handling facilities.

The oxygenation capacity was limited due to the 1 horsepower aerator, thus the organic loads which could be imposed on the system were restricted. In addition, difficulties in maintaining the feed rate were experienced due to heavy silt loads during processing of certain root crops which either wore out pumps or clogged feed lines.

Influent BOD concentration ranged from 260 mg/ℓ to over 1600 mg/ℓ which resulted in loadings of 3 to 12 pounds of BOD per day per 1000 cubic feet of volume. Percentage removals were generally in the 80 to 95 percent range. At this time it is difficult to say how much added benefit could be attributed to the tube settler as a result of the problems encountered. Hopefully, this will be answered during the next processing season if the manpower situation is such that the pilot plant can be operated for one more season.

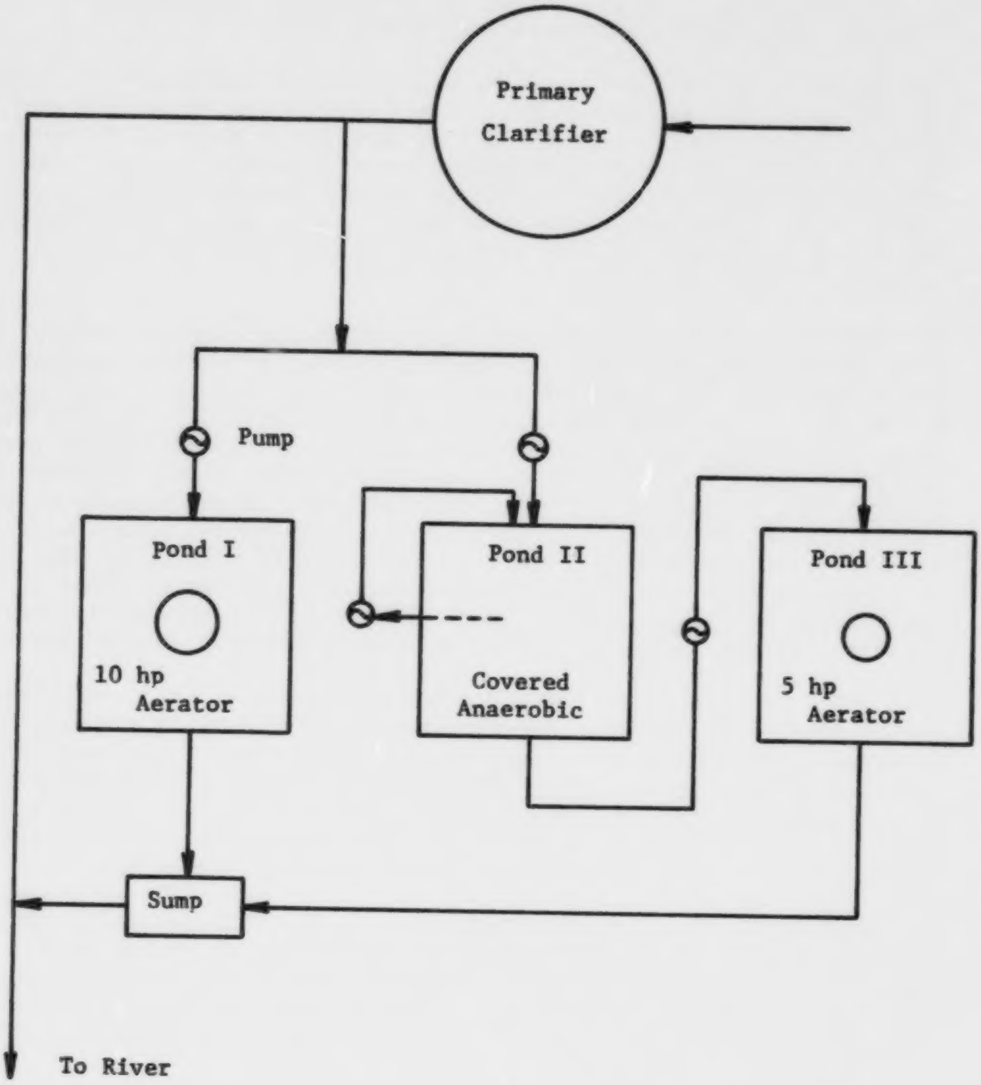
Primary
Clarifier
Pump
Pond I
10 hp
Aerator
Pond II
Covered
Anaerobic
Pond III
5 hp
Aerator
Sump
To River

Figure 2. FLOW DIAGRAM OF PILOT PLANT

The second pilot plant located at the cannery in Salem is called a Rotating Biological Contactor or RBC Unit. It consists of three units: a primary clarifier, the contactor, and a secondary clarifier. The contactor is a tank 14 inches deep, 18 inches wide, and 12 feet long containing 10 rows with 32 discs on each row. The 1 foot diameter discs are spaced at one-half inch intervals. Both the direction and the speed of rotation are controlled by valves and a hydraulic drive system.

As the discs are rotated about one-half submerged in the liquid, a biological film develops on the surface of the discs. This attached film absorbs and oxidizes the dissolved organics. In addition, the disc rotation aerates the liquid as it passes through the contactor. It is reported(3) that this type of process can be loaded much higher per unit volume than other biological systems due to the higher quantity of biological mass that is maintained in the system.

A combination of late arrival of equipment plus electrical and mechanical problems resulted in no reasonable length of operation of the pilot plant. It takes several days to build up a biological film on the discs. Almost continuous shearing of pins on the shafts containing the discs was experienced and this caused the biological film to slough. Thus, the unit was nearly always in the startup phase. It is hoped these problems have been solved and another season will result in some useful data.

Nearly all of the R&D effort within FWQA in the food processing field is in the grant program. At the present time (April 1970) there are 45 to 50 grant projects in various stages of completion. FWQA has contributed about $9 million to these studies which have total estimated project costs in excess of $24 million. Approximately three-fourths of these grants are in the area of responsibility assigned to the Corvallis Laboratory.

Twelve of these grant projects were reported on at the Symposium and the papers are in these Proceedings. In addition to these, a brief description of several of the other ongoing projects follows.

In addition to the two state-of-the-art summaries reported herein, three others have been awarded. The Beet Sugar Development Foundation located in Fort Collins, Colorado, is nearly finished with a similar document on the sugarbeet processing industry.

Ohio State University is preparing a state-of-the-art paper on the dairy industry and National Canners Association is handling the canned and frozen fruit and vegetable processing industries.

In the near future a contract will be awarded to cover the beverage industry--both alcoholic and non-alcoholic.

In addition to the state-of-the-art grant on the dairy industry there are five other R&D grants related to this industry.

Dairy Research and Development Corporation, New York, has a grant for development and full-scale demonstration of a process for the conversion of dairy whey into saleable food products. A dry powder will be produced from acid whey by evaporation and spray drying methods. The two year project is scheduled for completion by December 1970.

Crowley's Milk Company, Inc., of Binghampton, New York, has a 30-month grant to develop and demonstrate an ultrafiltration plant for abatement of pollution from cottage cheese whey. A two-stage ultrafiltration system with a capacity of 10,000 pounds per day will be designed, operated, and evaluated for separation and concentration of protein and lactose or for straight acid whey concentration. Phase II will include the demonstration of a full-scale (250,000 pounds per day) system.

Aerobic biological treatment of cheese processing rinse waters will be demonstrated by Kent Cheese Company, Kent, Illinois. Two lagoons will be operated in series, each with a hydraulic detention time of about 30 days. Oxygen will be supplied through submerged, 18-inch in diameter, aeration tubes by a compressor.

RAI Research Corporation had a small grant to investigate electrochemical oxidation of milk whey on a laboratory scale. Although it was shown that it is technically feasible to treat whey wastes in this fashion, the power consumption is high and the process is economically unattractive except for possibly the smaller plants. This work has been completed and the final report should be available in the near future.

Bench and pilot plant studies on secondary treatment of domestic sewage plus wastes from the manufacture of cheese and associated dairy products are underway as a result of a grant to the Village of Walton, New York. Both the trickling filter and activated sludge processes are being investigated along with methods aimed at improving sludge dewatering.

Seven grants currently underway are concerned with various aspects of meat slaughtering and processing.

Beefland International, Inc., Council Bluffs, Iowa, has a grant titled "Elimination of Water Pollution by Packing House Animal Paunch and Blood". This 18-month project will demonstrate the economic and technical feasibility of completely segregating blood and paunch from slaughterhouse operations and converting these materials into animal feed ingredients. Two dehydrators will be installed and utilized to process the material generated from anticipated cattle kills of 250 head per hour.

A 15-month project to demonstrate the application of anaerobic lagoons and two-stage trickling filters for the treatment of strong wastes resulting from the slaughtering and processing of hogs is nearly completed. This full-scale project is being done by Farmbest, Inc. in Denison, Iowa.

The University of North Carolina will conduct a two-year study for Gold Kist Poultry. It will involve changes in their processing operations for demonstration of effective inplant control of both water use and discharge of effluent from poultry processing.

A project titled "Construction and Study of A Demonstration Plant Utilizing the Aerobic Channel Method for Treating Packinghouse Wastes" is being conducted by John Morrell and Company in Ottumwa, Iowa. The objective is to find an efficient and economical method of treating raw packinghouse wastes so that they can be discharged to surface waters. Solids will be removed, dried, and tested for their possible use as an animal food supplement.

The feasibility of incineration of cattle paunch and ground manure will be demonstrated by Illinois Packing Company. Following segregation of waste streams for concentration of waste solids, a fluidized bed incineration unit will be operated to develop the optimal performance and related economics.

A grant was awarded to Stockton, California, for a full-scale development and demonstration of pretreatment of packinghouse waste using high-rate activated sludge plus in-sewer treatment to reduce the BOD load to the municipal system by about 80 percent. It is hoped that the in-sewer treatment will result in significant savings in capital expenditures on the activated sludge plant.

The City of South St. Paul, Minnesota, has a grant titled "Efficiency and Economy of Polymeric Sewage Clarification". The principal objective is to determine the increased purification attainable by treating various combinations of packinghouse waste, domestic sewage, and stormwater with polyelectrolytes and floc weighting agents.

Two projects are concerned with wastes from the beverage industry.

Widmer's Wine Cellars, Inc., Naples, New York, has a grant to design, construct, and operate an extended aeration waste treatment plant to treat winery processing wastewaters. Each of two parallel systems will consist of an aeration basin, clarifier, and a sand filter. Design loading is about 10 lbs. BOD/day/1000 cu.ft. with a hydraulic detention time of about 6.5 days.

The Agricultural Experiment Station, University of Puerto Rico, has a project aimed at evaluating the efficiency and the economics of several processes for treatment of rum distillery wastes. Pilot plant work is scheduled on lagooning, activated sludge, and anaerobic digestion.

In addition to the two projects on potato processing wastes discussed at the Symposium there are two other full-scale R&D grants concerned with these wastes.

Western Potato Service, Inc. of Grand Forks, North Dakota, will demonstrate at full-scale the economics and the pollution reduction characteristics of a potato "dry" caustic peeling system. A similar full-scale processing plant which employs conventional caustic peeling will be monitored for comparison. The dry caustic peeling process was originally conceived and developed by the Western Regional Research Laboratory of the U. S. Department of Agriculture in Albany, California. This process has the potential of reducing the water use of a processing plant by 50 percent and reducing the quantity of BOD and SS discharged by 50 to as much as 75 percent.

A full-scale demonstration and evaluation of joint treatment of municipal sewage and potato processing wastes is being done by Grand Forks, North Dakota. Four lagoons, each with a capacity of 8.4 million gallons will be used for treatment prior to discharge of the wastes into 640 acres of existing stabilization ponds. Two of the lagoons will be completely mixed, covered anaerobic units and two will be completely mixed aerobic units. Planned operation of the facility is for one-half of the combined waste to be added to an anaerobic cell followed, in series by an aerobic cell. The remaining waste will be divided between the other anaerobic cell and the other aerobic cell.

The City of Tualatin, Oregon, has a project entitled "Tertiary Treatment of Combined Domestic/Industrial Wastes". About 25 percent of the BOD load is generated from the manufacture of dog food. During 6 months of the year activated sludge treatment followed by high-rate filtration and chlorination will suffice. During the critical 6 months of low stream flow chemical addition, flocculation, and sedimentation of the activated sludge effluent prior to filtration will be practiced for phosphate removal. Alternate methods of final disposal of waste activated sludge and the chemical sludge will be investigated.

Corn Products Company is demonstrating secondary treatment of wastes from the wet-milling industry. The three and one-half year project entails the design, construction, and operation as well as a technical and economical evaluation of a one million gallon per day completely-mixed aerobic system.

"Removal and Recovery of Fatty Materials from Edible Fat and Oil Refinery Effluents" is the title of a grant which has been awarded to Swift and Coma ny. The 18-month study is being conducted at their Bradley, Illinois, plant and will demonstrate the effectiveness and economics of air flotation for removal and recovery of fatty materials present in their processing wastewaters.

Melbourne Water Science Institute in Australia has a grant titled "Cannery Waste Treatment by Lagoons and Oxidation Ditch". Existing 100,000 gallons per day facilities are being used during the two-year study to evaluate and optimize treatment of fruit and vegetable processing wastes by anaerobic lagoons and oxidation ditches.

A grant to National Canners Association will demonstrate the effectiveness of an ion exchange system for the treatment of olive brine process water. Operating parameters as well as scale-up factors will be determined from the 10,000 gallon per day pilot unit which will use calcium hydroxide as a resin regenerant.

Although not directly related to the R&D effort on food processing waste treatment it is worthwhile to list several points President Nixon made in his February 10, 1970, message to Congress on the environment.

The major industrial pollution problem was listed as: "Regulations on disposal of industrial wastes have been too weak to prevent increasing water pollution." The Administration proposal was: "Reform pollution control program to greatly strengthen regulations on industrial and municipal polluters and permit swift enforcement actions."

Seven of the specific items from the 37 Point Program as presented by President Nixon are:

1. "Requirement that municipalities impose users fees on industrial users sufficient to meet costs of treating industrial wastes.

2. Extension of Federal-State water quality standards to include precise effluent standards for all industrial and municipal sources.

3. Provision that violation of established water quality standards is sufficient cause for court action.

4. Revision of Federal enforcement procedures to permit swifter court action against those in violation of water quality standards.

5. Authorization for the Secretary of the Interior to seek immediate injunctions where severe water pollution threatens imminent danger to health or irreversible damage to water environment.

6. Extension of Federal pollution control authority to include all navigable waters, both inter- and intra-state, all interstate ground waters and the United States' portion of boundary waters.

7. Provision that violation of established water quality standards is subject to court-imposed fines of up to $10,000 per day.

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STATUS AND RESEARCH NEEDS OF POTATO PROCESSING WASTES

by

Kristian Guttormsen and Dale A. Carlson*

INTRODUCTION

The potato processing industry in the United States has experienced tremendous growth during the last decade, and future projections indicate that this trend will continue. The total annual production of potatoes in this country was about 15 million tons in 1966, an increase of 25 percent since 1956. Over the same period of time, the tonnage processed increased by almost 150 percent(1). In 1966, approximately 35 percent of the total crop was used for processing. In a study of the Pacific Northwest by the Department of the Interior(2), a potato production increase of 83 percent was predicted for the period from 1965 to 1985. Over the same 20-year period, the production of frozen and dehydrated potato products was expected to increase by approximately 250 percent.

The highest rate of growth of the potato processing industry has occurred in Idaho, where more than 50 percent of the total production has been processed since 1960. Unfortunately, the waste production has increased accordingly, and potato wastes have become one of the major water pollution sources in the state. Although all of the major processors now provide primary treatment, severe fish kills have occurred on the Snake River during periods of low flow. As a result, the processors have been directed by the Idaho State Health Department to provide secondary treatment of their wastes(3). By the summer of 1973, all the plants will be required to have such facilities in operation. Similar enforcement policies are in effect across the nation.

WASTEWATER PRODUCTION

A variety of potato products is marketed today, and processing methods and waste production vary from plant to plant. The J. R. Simplot Company's three processing plants at Burley and Heyburn, Idaho, process about 300,000 tons of potatoes per year. During the 1966-67 processing season, these three plants used an average of 4,170 gallons of water per ton of potatoes processed. The waste stream contained an average of 90 pounds of BOD and 110 pounds of suspended solids per ton of potatoes. Total nitrogen and phosphate amounted to 3.5 and 0.6 pounds per ton, respectively. These figures were derived from the flows entering the primary clarifier, and do not include fat recovered and solids screened out. As a result of lye peeling, the raw waste had a pH of 11.3. The suspended solids and BOD values were higher than experienced during previous years. Average values for the potato processing industry are about 4,200 gallons, 60 pounds of suspended solids and 50 pounds of BOD per ton of potatoes processed(4).

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PRIMARY TREATMENT

Because potato wastes contain high concentrations of settleable suspended solids, sedimentation has been a relatively effective treatment method. It has been estimated that after the installation of primary treatment facilities in the Idaho processing plants, the waste load reduction was equivalent to the waste from three million people(5).

Treatment facilities range from settling ponds used for flume and wastewater to more sophisticated mechanical clarifiers especially designed for potato waste. Sedimentation studies conducted in Idaho concluded that primary clarifiers should be designed for a maximum overflow rate of 600 gpd/ft^2, with detention times of 2.5 to 3 hours(5). By proper design of the sludge rake mechanisms and control of the sludge return, clarifier underflows with solids concentrations of 6 to 7 percent could be obtained. Clarifiers designed according to these criteria were expected to reduce the BOD by 60 percent and the suspended solids by 90 percent.

High removal efficiencies have been reported from field installations. Average results from two processing seasons (1966-67 and 1967-68) at the J. R. Simplot Company's waste treatment plant in Burley, Idaho, were 41 percent BOD removal and 73 percent suspended solids removal. The 100-foot diameter clarifier was operated at an average overflow rate of 800 gpd/ft(4). Simplot's waste treatment plant in Caldwell, Idaho, consists of grease removal facilities, three rotary screens with 4-mesh cloth, and a clarifier 100 feet in diameter. Plant performance for the 1967-68 processing season was 62 percent COD removal, 93 percent suspended solids removal, and 95 percent settleable solids removal. The overflow rate of the clarifier was about 730 gpd/ft^2(5).

Attempts have been made to improve primary clarifier performance by using chemical coagulants(6). However, significant improvements over plain sedimentation was not achieved. Some success has been reported on flotation treatment of potato waste(7). A pilot plant study conducted by the Potato Products Waste Disposal Executive Committee for the Red River Valley gave suspended solids removals in excess of 90 percent and BOD removals as high as 75 percent.

Centrifugation has also been proposed as a means of treating potato waste, especially flume and wastewater, but studies by the Potato Processors of Idaho Association did not find this method a feasible replacement for conventional clarification(5, 8).

Disposal of the large volume of solids recovered by primary clarification appeared to be a major problem until it was discovered that the sludge could be dewatered and used for cattle feed. Vacuum filtration has been found to be the best method for dewatering the sludge. Centrifugation and screening have been considered as well, but have not proved as successful as vacuum filtration(5). It was found that sludge from plants using steam peeling could be dewatered to a concentration of 12 to 16 percent dry solids. The filtrate contained suspended solids in concentrations of 1,000 to 1,200 mg/1, most of which would settle when the filtrate was returned to the clarifier. Sludge from plants using lye peeling appeared to be impossible to dewater because water would not separate from the solids and the gelatinous slurry would blind the filter cloth. By chemical treatment of the sludge with ferric sulfate and lime, it was found that the caustic sludge could be dewatered at about the same rate as steam-peel sludge. However, the filter cake could not be used for cattle feed because of the chemical content, and the chemical costs were high. It was finally discovered that by aging the sludge in the clarifier, the sludge becomes filterable. Bacterial action breaks down the gelatinous consistency. Close control is necessary because holding the sludge too long results in bacterial decomposition of the solids with reduced filterability and lower clarifier efficiency.

The potato solids have been proven to be at least equivalent to barley in nutritional value, and feeding experiments have indicated substantial acceleration of weight gain in cattle after potato solids were included in the diet. At the present, most of the Idaho processors are selling the dewatered sludge along with screen solids for approximately $3 per ton of solids at about 14 percent dry solids content. According to Grames and Kueneman(5), this is sufficient to recover the capital cost of primary treatment facilities in two to four years.

SECONDARY TREATMENT

The majority of the potato processors do not provide secondary treatment of their wastes at the present, and operational results from secondary facilities are therefore practically non-existent. A considerable amount of research has been carried out, however, in bench-scale and pilot plant studies.

Atkins and Sproul(9) studied the feasibility of using the complete mix activated sludge process to treat the combined waste from a processing plant using lye peeling. At loadings above 300 lbs BOD/1,000 cu ft/day, BOD removals in excess of 90 percent were obtained without pH adjustment or inorganic nutrient addition. The consulting firm of Cornell, Howland, Hayes and Merryfield conducted pilot plant studies for the Potato Processors of Idaho Association(3). It was found that the complete mix activated sludge process operated best at loadings below 150 lbs BOD/1,000 cu ft/day, BOD removals above 90 percent were obtained. Excess sludge production was a problem as about one pound of biological solids were produced per pound of BOD removed. It was also anticipated that nutrient addition would be required in a full-scale plant.

Last year, a full scale complete mix activated sludge plant was put into operation at the Pillsbury Company's processing plant at Grafton, North Dakota(10). The design loading was 400 lbs BOD/1,000 cu ft/day. The effluent which was expected to contain 200-400 mg/l BOD was to be discharged to a municipal sewer for further treatment.

The contact stabilization process has also been applied to potato waste, but not as successfully as the complete mix process(3, 9).

Pilot plant studies on trickling filters have been conducted by the Potato Processors of Idaho(3). At loadings of 400 lbs BOD/1,000 cu ft/day, the filter, which had artificial media, was capable of 75 percent BOD reduction. Nutrient addition was found to be advantageous, but no pH adjustment of lye-peeling wastes was necessary. It was concluded that addition of alkalinity might be required when treating steam-peel waste to prevent the pH from dropping. Sludge production was found to be on the order of 0.6 to 0.8 pounds per pound of BOD removed.

Trickling filter treatment of protein water from a starch plant gave BOD reduction of 90 percent at loadings of 30 lbs BOD/1,000 cu ft/day. With a high rate filter, BOD removals of 90 percent were obtained at loadings up to 70 lbs BOD/1,000 cu ft/day. The rock media filter became clogged with sloughed solids at higher loadings(11).

Recently, the anaerobic filter has received attention as a potential treatment process for potato waste. The anaerobic filter, which is similar to the aerobic tricking filter in appearance, has upward flow so that the rock media is completely submerged. The anaerobic organisms are attached to the stones as well as suspended as discrete particles in the interstitial spaces. High solids retention time, which is an important operational parameter in anaerobic processes, is easily obtained in the filter and may be on the order of hundreds of days(12).

Pilot plant studies in Idaho(6) gave BOD removals of almost 70 percent when the filters were loaded at about 60 lbs BOD/1,000 cu ft/day. Two 5-foot diameter filters were tested, one with a 4-foot media depth and one with an 8-foot depth. Almost identical performance was obtained with both filters. The gas produced had a methane content of more than 70 percent and is therefore combustible. In a full-scale plant, the gas could be used as an energy source. The effluent from an anaerobic filter should be passed through a short-term aeration basin to provide additional organic removal and render the effluent suitable for discharge to a receiving stream. With primary treatment, this system appears capable of 90 percent BOD removal. Some possible limitations of the anaerobic filter have been reported by Young and McCarty(13).

Stabilization ponds or oxidation ponds have long been a popular and economical method of waste treatment. Porges(14) made a survey of industrial stabilization ponds in the United States in 1962. He reported three ponds treating potato processing wastes. The median loading and detention time of the ponds were 111 lbs BOD/acre/day and 105 days, respectively. No treatment efficiencies were reported, but one of the installations was reported effective while another caused odor nuisances. Studies by Cornell, Howland, Hayes and Merryfield(3) concluded that pond loadings should be kept well below 80 lbs BOD/acre/day, and in general ponds should be designed according to criteria used for domestic waste.

Ponds at Grafton and Park River in North Dakota have been studied extensively(15, 16). These ponds received domestic waste as well as potato processing waste. Both ponds have been heavily overloaded by potato waste during the processing season. During the winter, the ponds were ice covered and acted merely as storage ponds. When biological activity was reestablished in the spring, anaerobic conditions developed, and severe odors were experienced. Nevertheless, it was concluded that potato waste and domestic waste digested readily in the ponds when the organic loading from potato wastes was 15 times or more the domestic loading. During the summer, the combined waste could be applied at loading rates well above the conventional design loading for northern climates of 20 lbs BOD/acre/day. Although no recommendations could be made from the study because of the "diametrically opposed" operating seasons for the pond and processing plant, it was indicated that loadings on the order of 50 to 60 lbs BOD/acre/day might be possible.

Although anaerobic ponds have been used extensively for treatment of food processing wastes, they have not yet been used to any extent by the potato processors. Porges(14) reported that in 1962, three anaerobic ponds were used in the United States for potato wastes. No information was given on the efficiency of the ponds, but it was reported that odor nuisances were associated with one of them.

Efforts by the Potato Processors of Idaho to establish design criteria for anaerobic ponds gave encouraging results. In a completely mixed anaerobic pond loaded at 8 lbs BOD/1,000 cu ft/day, average BOD removals of 70 percent were obtained(6). An unmixed pond operated in parallel achieved only 40 percent reduction. The effluent from the mixed pond was treated in an aerated cell for further removal and oxygenation. With primary treatment, this system appears capable of 90 percent BOD reduction without pH adjustment or nutrient addition.

Aerated lagoon treatment has also been investigated. Reductions of 85 percent BOD were obtained in a one-acre experimental lagoon at Park River, North Dakota, at temperatures close to 0° C. The detention time was 14 days(17). Pilot plant studies in Idaho gave total BOD reduction of approximately 80 percent and soluble BOD reduction in excess of 90 percent. The detention time was 7.8 days and the temperature about 7° C (4).

Spray irrigation has been used successfully in this country as well as in Europe as a method of final disposal of potato waste(8, 18, 19).

IN-PLANT WASTE LOAD REDUCTION

The importance of in-plant efforts to reduce the total waste load can hardly be overemphasized. Capital and operating cost of waste treatment facilities are closely related to the volume and organic content of the waste, and the cost of in-house modifications will generally represent substantial savings in the cost of treatment facilities. Now that secondary treatment will be enforced, in-house waste reduction efforts will be most important.

Excessive use of water is common in many processing plants, and with proper control the total use can often be reduced by 50 percent. Reuse of processing water is becoming more common among the processors, and large savings are obtained this way. Flume and wash water, for example, are low in BOD and dissolved solids and can be reused following minimal treatment to remove silt, debris, and large solids. A special form for reuse is counter-current flow of process water. This scheme is especially attractive in processes with successive washes and rinses, since the product is moved forward after each washing into water which is cleaner than that used in the preceding wash. This principle is being used for final purification of starch(20).

Good housekeeping and in-plant removal of solids are very important. Potato peel and pulp contain 0.1 mg of BOD per mg of dry solids(21), and solid matter should therefore be removed from the waste stream as fast as possible to avoid leaching of organics, especially in warm water. Experiments by Sproul(22) showed that in 30 minutes 150 grams of sliced potatoes leached about one-half gram of soluble BOD. Various types of screens are presently used to remove solids in the plant.

The peeling operation contributes the major waste load from a potato processing plant, and much attention has been given to improvement of this process. Two types of peeling processes are used extensively today, steam peeling and lye peeling. Abrasion peeling is also used. All these processes use large quantities of water and impose large solids and BOD loads on the waste stream.

Presently, work is underway on two newly developed "dry" peelers. These peelers were developed at the Western Regional Research Laboratory of the United States Department of Agriculture at Albany, California, and at the Institute for Storage and Processing of Agricultural Produce (IBVL) at Wageningen in Holland.

The peeler developed in this country applies infrared radiation to caustic-treated potatoes. The softened skin is removed abrasively without use of water, and the potatoes are given a final brush washing before they are discharged from the peeler assembly. A pilot plant installation in Idaho had a capacity of about 5,500 lbs of potatoes per hour. The water use was about 280 gallons per hour or 100 gallons per ton of potatoes. This represents a water use reduction of more than 80 percent with respect to steam or lye peeling. The process was frequently compared with a conventional lye-peeler, and trim losses were taken as an indication of the effectiveness of peel removal. When the efficiency of the two lines were approximately equal, it was found that the peeling loss on the dry-peel line was 13 percent, while the loss on the conventional line was about 20 percent. The caustic use was reduced by 70 percent on the dry-peel line as compared to the conventional line. Based on the limited amounts of data collected during the study, it was estimated that the total waste load to secondary treatment facilities could be reduced by at least 50 percent(23). Additional work on a larger scale is underway to evaluate the overall economics of the method.

By-product recovery from potato processing and process waste has received considerable attention. As mentioned earlier, primary sludge and screened solids are being sold or used for cattle feed. A symbiotic yeast process has been developed by the Swedish Sugar Corporation(24). Process water is used to make a growth medium for the yeast Torula. The product may be used as a feed additive or for human consumption. In addition to the yeast production, a considerable BOD reduction was also achieved.

Considerable work has been conducted on by-product recovery from starch plant wastes. Presently, research is underway at the Eastern Utilization Research and Development Division of the U. S. Department of Agriculture(25). The proposed treatment process would consist of five steps: concentration of dilute waste by reverse osmosis; precipitation and recovery of protein by steam injection or other suitable methods; separation and recovery of potassium and other inorganic cations by ion exchange; separation and recovery of amino compounds by ion exchange; and recovery of organic acids and phosphates by ion exchange. Promising results have been obtained.

RESEARCH NEEDS

With the existing waste treatment technology, any reasonable effluent quality requirement imposed on the potato processing industry can be met. In England, where effluent requirements are considerably more restrictive than in the United States, potato waste treatment facilities capable of producing effluents with BOD and suspended solids concentrations below 20 mg/l are in operation. In one such plant, primary sedimentation is followed by two stages of biofiltration and activated sludge treatment. Final polishing on sand filters enables reuse of a large fraction of the effluent in the processing operations without detrimental effects on the quality of the final product. A treatment scheme such as this is, of course, costly, and cost is the main treatment problem facing most potato processors. Capital as well as operating costs are high, with little or no possibility for return on the investments.

Many possibilities exist for reducing the amount of waste from potato processing and improving the waste treatment technology; a great deal of work has already been done to alleviate the potato waste problem. However, with all due respect to previous and present efforts, there is always room for further improvements.

In-plant changes and modifications may be the most important area of concern. The peeling operation, which contributes from 50 to 75 percent of the total plant waste load, must be improved in order to reduce the waste load significantly. Very promising results have been obtained with the dry caustic peeler previously described. However, more work is required to perfect this process. Handling, disposal, and utilization of the slurry produced from the peel and wastewater must be investigated. The economics of the process compared to other peeling methods also must be demonstrated.

The rest of the processing operations should be considered as well. Solids losses and water usage must be reduced, since these increase the waste load as well as the total loss from the process. Improved equipment and methods for slicing, blanching, cooking, etc. should be developed. In the same respect, firm guidelines for good housekeeping should be established, and process line personnel should be educated in waste prevention.

A certain loss of solids will always occur. Preferably, these solids should not be allowed to enter the waste stream. If they do enter the wastewater, then as much as possible of these solids should be removed in the processing plant before considerable leaching of organics takes place. Removal may be achieved by screening, filtration, or centrifugation. In this respect, research is needed on suspended solids particle size in relation to screening. Fragmentation of the particles on the screen may increase the apparent BOD. A similar phenomenon may take place in the centrifuge. The solid particles may be broken down by the centrifugal force and thus remain in the centrate. It has been reported that this indeed happens when primary potato sludge is dewatered by centrifugation. The small particles discharged with the centrate have poor settling characteristics and thus are not removed easily by sedimentation.

Reuse of process water has been discussed earlier. Besides removal of suspended solids, quality control of the water must be investigated. Various methods of microbial control should be evaluated to control deterioration of the recirculated water. The tolerance limits for different pollutants should be established for various steps in the process on a health hazard basis as well as on a product quality basis.

Separation of various waste streams may be advantageous for subsequent treatment in different systems. Waste concentration also may prove very advantageous since concentrated waste can be treated more efficiently than dilute waste. Concentration and separation by reverse osmosis is one possibility which presently is being investigated.

The concentrated portion of the waste stream may be subjected to recovery of various valuable constituents while the separated dilute portion may be reused in the processing operations. The present research efforts are directed towards potato starch plant waste. Feasible application of this or similar processes to other types of potato wastewater should be investigated.

A variety of salable by-products can be recovered from the various waste streams, and considerable research has been conducted in this field. Few large-scale, economically feasible processes have been developed, however.

Some of the compounds which may be recovered from potato waste include amino acids, protein, organic acids, potassium, phosphates, and other inorganic ions. All these compounds have been recovered by physical or chemical processes.

Potato pulp and wastewater may also be used as growth media for yeasts and molds for production of protein and antibiotics. Promising results have been obtained with the yeast Torula.

A number of edible products for human consumption have been proposed from larger potato solids. Utilization of potato solids for livestock feed has found wide acceptance.

In order to take advantage of these possible by-products from potato wastes, feasible processes and a market must be developed. The present efforts on by-product recovery are concentrated mainly on starch plant waste, since the potato starch industry is a rather marginal industry. More emphasis should be directed towards recovery of salable products from other types of potato processing waste.

The ultimate solution to the waste treatment problem would be to produce an effluent which could be completely reused in the processing operations. Although such a goal is rather impractical at the present time, the possibility of effluent reuse nevertheless should be kept in mind. In order to solve the more contemporary problems facing the potato processors, existing and proposed technology must be improved and modified to give more efficient, less costly waste treatment. The most pressing problem at present is secondary treatment, a requirement which is facing most of the processors across the nation. However, continued efforts to improve primary treatment methods should not be ignored since primary treatment can reduce the load on the secondary treatment facilities significantly.

Potato processing wastes have been found easily degradable by biological treatment processes, and considerable progress has been made in their application to potato waste treatment. A significant amount of pilot plant work has been done, but operational results and experience from full-scale installations are limited. Research needs for biological treatment processes are not unique to potato processing wastes but apply to most industrial wastes. In general, better prediction models for the different processes must be developed. The values of the model factors, i.e., removal rate constants, growth rate constants, etc., and their variations with waste quality parameters, should be determined more precisely. More specifically, the availability of the essential nutrients, such as nitrogen and phosphorus, for adequate treatment should be investigated. The amount of nutrients in potato waste is generally sufficient for effective biological treatment, but the nutrients may not be readily available for cell incorporation. The effects of conditions or compounds directly inhibitory to biological treatment, such as high pH, antifoaming agents and cleaning compounds, should be studied further.

Promising results have been obtained with the anaerobic filter, the anaerobic contact process and anaerobic ponds, and work on these processes should be continued. Special attention should be given to start-up characteristics, duration of start-up period, optimum operating conditions, and solids-liquid separation. Solids disposal also should be considered.

High-rate chemical oxidation processes have not been found economically feasible at the present. Further research on these and other chemical and physical processes should be conducted, especially with regard to more complete reuse of treated effluents.

Conventional primary treatment and biological secondary treatment produce excessive solids. Primary sludge has been used successfully for cattle feed. The possiblity of utilizing secondary sludge in a similar way should be investigated. The economics of other solids disposal methods should be evaluated since little is known about the feasibility of secondary sludge for cattle feed and since there may not be a market for this product. Efficient and economical methods for dewatering dilute sludges should be developed, along with methods for handling sludge with high solids content(26).

SUMMARY

Several treatment processes have been found economically feasible for secondary treatment of potato processing wastes, and large sums of money need not be spent to study these processes further. Efforts should be made to reduce the capital cost and operation and maintenance cost of secondary treatment facilities. Future research should be directed mainly towards the processing plant in order to reduce the waste production and recover valuable by-products.

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AEROBIC SECONDARY TREATMENT OF POTATO PROCESSING WASTES

by

Glenn A. Richter*

INTRODUCTION

The purpose of this paper is to report the progress being made on a government demonstration grant project at the R. T. French Company's potato processing plant at Shelley, Idaho.

The primary objectives of the grant are to:

1. Demonstrate the feasibility of secondary treatment of potato processing wastes by a fully aerobic process.

2. Determine BOD (biochemical oxygen demand) removal efficiencies when the treatment facility is operated as:

    A. A complete mix activated sludge system

    B. A flow-through aeration system without sludge return

    C. An intermittent aeration system with periods of aeration, clarification, and supernatant drawoff

3. Determine the quantity and character of waste biological sludge produced during aerobic stabilization of potato processing wastes.

4. Define the influence of: foaming, ice, temperature, pH, nitrogen, and phosphorous on treatment.

5. Determine the operating costs for the methods of treatment demonstrated.

PLANT INFLUENT CHARACTERISTICS

Potato processing plant wastewater can be divided into two major streams: (1) silt water and (2) process water. The silt water originates from raw potato washing and fluming operations. It contains large amounts of soil removed from the raw potatoes. Process water flows from potato processing operations, where raw potatoes are processed into packaged, partially cooked food products. It contains caustic potato peeler and barrel washer discharges, as well as all other liquid wastes from the processing operations, including clean-up water.

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Total secondary treatment plant influent contains primary clarified process water and clarified silt water. Characteristics of the total plant influent are described below:

Alkalinity, pH, and Temperature - Total plant influent alkalinity varied from 70 mg/l to 5740 mg/l, with an average of 1730 mg/l as $CaCO_3$. The pH varied from 6.8 to 11.5, and averaged 9.3. The influent temperature varied from 12°C to 24°C. The average temperature was 20°C.

BOD and COD - The BOD of the total plant influent varied from 780 mg/l to 2990 mg/l. The average BOD was 1680 mg/l. 65 to 70 percent of the total influent BOD was in a soluble form. The COD of the influent varied from 760 mg/l to 7100 mg/l, with an average of 3050 mg/l. The average BOD:COD ratio was 0.55.

Suspended Solids - The TSS (total suspended solids) concentration in the total plant influent varied from 320 mg/l to 6460 mg/l. The average TSS was 1430 mg/l. VSS (volatile suspended solids) averaged about 90 percent of the TSS.

Nutrients - On the basis of a limited amount of testing, the average nitrogen and phosphorous concentrations in the total plant influent were not limiting factors. The average BOD:N:P ratio was equal to 100:4.5:0.6.

PLANT DESCRIPTION

Design Criteria - The criteria used for the final design of the secondary treatment facilities at the R. T. French Company are listed in Table 1.

Plant Operation - An aerial photo of the new secondary waste treatment facility is shown on Figure 1, and the treatment facility flow diagram is shown on Figure 2. A general description of the flow patterns of the plant is given in the following paragraphs.

Primary clarified potato process wastewater flows by gravity to the influent pump pit where it is combined with clarified silt water. This total plant influent is then pumped to the aeration basin inlet-outlet structure, where the flow can be divided, as desired, between the two aeration basins. The incoming wastewater is dispersed throughout each of the aeration basins by floating mechanical aerators.

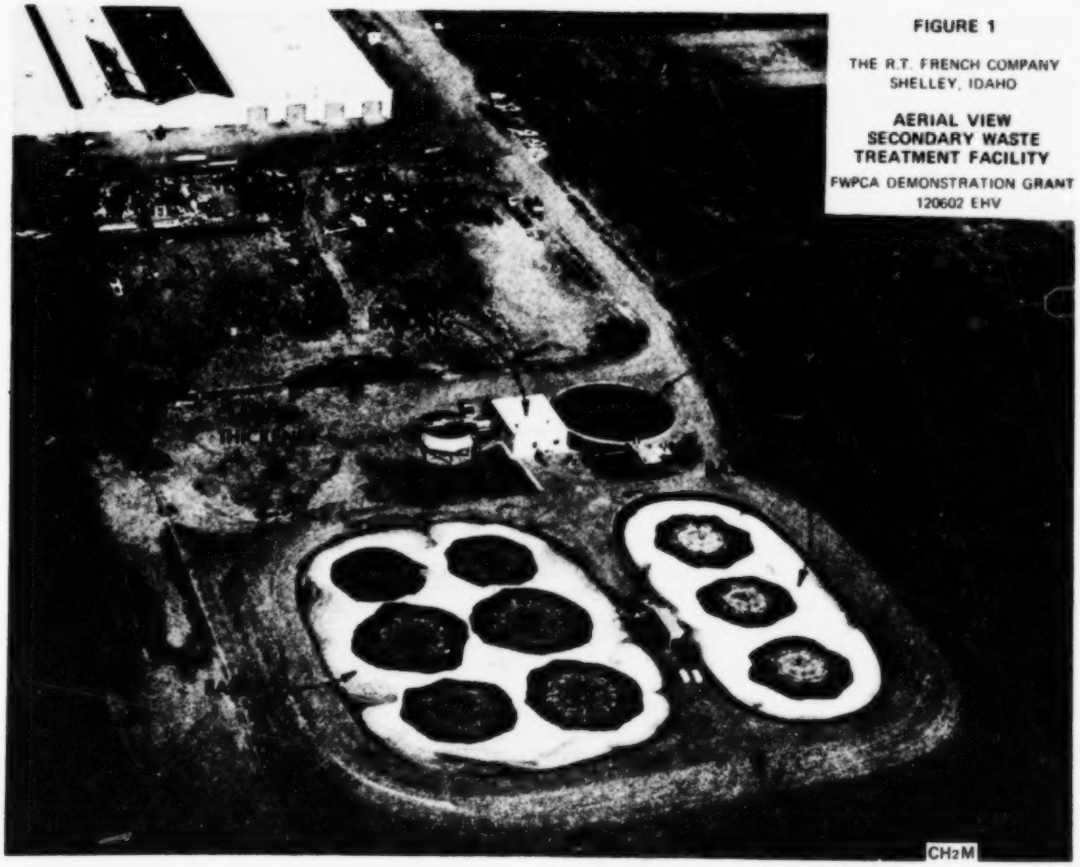

FIGURE 1

THE R.T. FRENCH COMPANY
SHELLEY, IDAHO

**AERIAL VIEW
SECONDARY WASTE
TREATMENT FACILITY**

FWPCA DEMONSTRATION GRANT
120602 EHV

CH2M

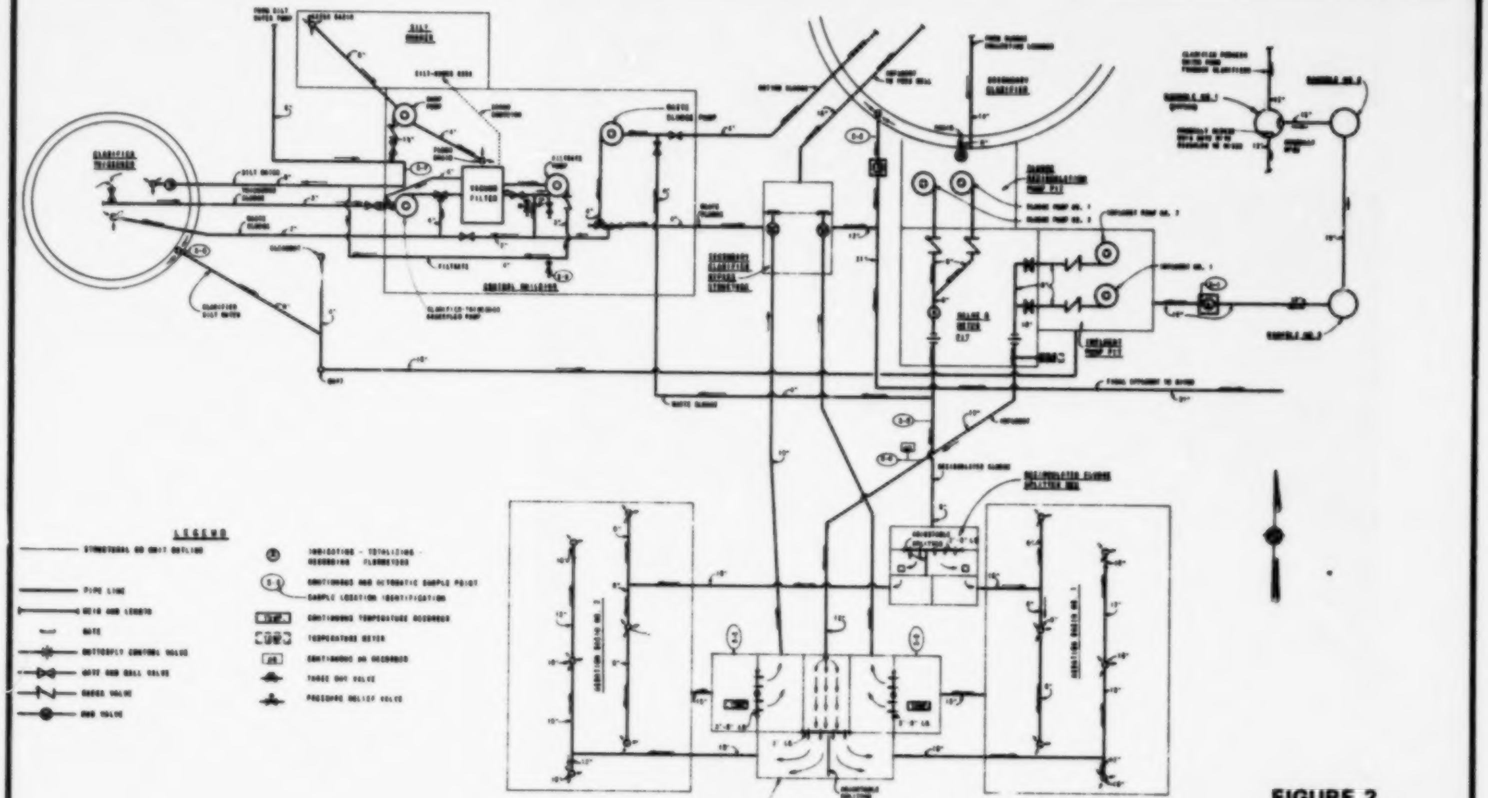
LEGEND
PIPE LINE
GATE
BUTTERFLY CONTROL VALVE
INDICATING - TOTALIZING - RECORDING FLOWMETERS
CONTINUOUS AND AUTOMATIC SAMPLE POINT
SAMPLE LOCATION IDENTIFICATION
CONTINUOUS TEMPERATURE RECORDER
TEMPERATURE METER
CONTINUOUS pH RECORDER
THREE WAY VALVE
PRESSURE RELIEF VALVE
VACUUM FILTER
SECONDARY CLARIFIER
AERATION BASIN NO. 1
AERATION BASIN NO. 2

FIGURE 2

THE R.T. FRENCH COMPANY
SHELLEY, IDAHO

FLOW DIAGRAM
SECONDARY WASTE
TREATMENT FACILITY
FWPCA DEMONSTRATION GRANT
120802 EHV

CH2M

84435.8

Effluent from the aeration basins flows by gravity back through the aeration basin inlet-outlet structure to the clarifier bypass structure. The flow is normally directed to the secondary clarifier, but may be bypassed during an emergency at the clarifier bypass structure for discharge to the Snake River.

Effluent from the secondary clarifier flows to the Snake River.

Table 1. Secondary Treatment Plant Design Criteria

Average Daily Flow		
Waste Process Water (mgd)		1.0
Waste Silt Water (mgd)		0.25
	Total	1.25
Peak Flow Rate		
Waste Process Water (gpm)		836
Waste Silt Water (gpm)		400
	Total	1,236
BOD		
Waste Process Water (lbs/day)		13,700
Waste Silt Water (lbs/day)		400
	Total	14,100
TSS		
Waste Process Water (lbs/day)		5,680
Waste Silt Water (lbs/day)		940
	Total	6,620

Settled lightweight sludge flows by gravity from the bottom of the clarifier to the sludge collection launder. It then flows by gravity from the sludge launder to the sludge recirculation pump pit. The sludge is then pumped to the recirculated sludge splitter box, where it can be divided into two portions of desired size and returned to the two aeration basins.

Dense settled solids are pumped from the sludge hopper in the bottom of the clarifier to either the vacuum filter or to the clarifier-thickener. This waste sludge may also be pumped to the clarifier bypass structure for discharge to the river.

The waste sludge, pumped to the clarifier-thickener, is concentrated along with silt water. Clarifier-thickener overflow is transferred by gravity to the influent pump pit. The thickened sludge is pumped from the bottom of the clarifier-thickener to the vacuum filter, where it is dewatered along with any waste sludge pumped directly to the filter.

Solids discharged from the vacuum filter are conveyed to the silt bunker in a cake form. This cake is then hauled away by trucks for ultimate disposal as landfill.

Unit Sizes - The major treatment units of the secondary treatment facility are described below.

Figure 3 shows Aeration Basin 1, which has a capacity of 1.25 mgd and holds three 50 hp floating mechanical aerators. Aeration Basin 2, shown on Figure 4, has a capacity of 2.5 mgd and normally utilizes six 50 hp floating mechanical aerators. Both basins have a water depth of 16 feet, and a design BOD loading of 28 lb/1000 cu. ft/day.

The secondary clarifier (Figure 5) is 70 feet in diameter and has a 12-foot side water depth. The clarifier has a rapid sludge withdrawal mechanism, and a hydraulic overflow rate of 325 gal/sq ft/day at design flow.

Figure 6 shows the treatment facility control building. The control building houses the vacuum filter, sampling and testing laboratory facilities, and various sludge handling facilities. The vacuum filter is a disc type and has a surface area of 300 square feet.

Figure 7 shows the clarifier-thickener which is 30 feet in diameter. The side water depth is 18 feet and the hydraulic overflow rate is 860 gal/sq ft/day.

Operation Schedule - During the test period, the secondary treatment facility received wastewater flow on a schedule parallel with the operating schedule of the potato processing plant. The processing plant operated almost continuously, except for a two-day shut down on weekends for clean-up and repairs. Cleaning water flow during processing shutdowns was directed to the treatment facility.

Primary clarified process water was directed to the secondary treatment facility by adjusting slide gates in Manhole 1 (see Figure 2). The amount of process water discharged to the facility was determined by the aeration basin operation. All process water entered the facility during normal operation. Screened silt water was directed to the clarifier-thickener by silt water pumps in the storage cellars. Potato processing seasons are about 9 to 10 months long.

PLANT PERFORMANCE

The secondary waste treatment facility has operated from September 3, 1969, through the present time. Operating data are included through March 31, 1970.

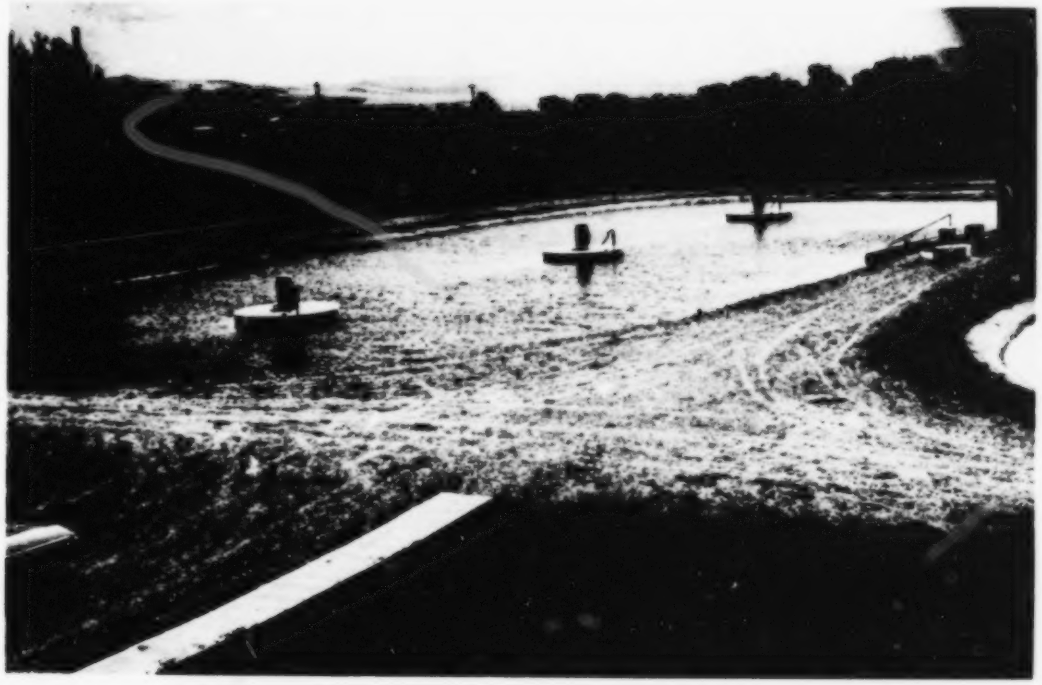

Figure 3. The R. T. French Company, Shelley, Idaho

AERATION BASIN 1

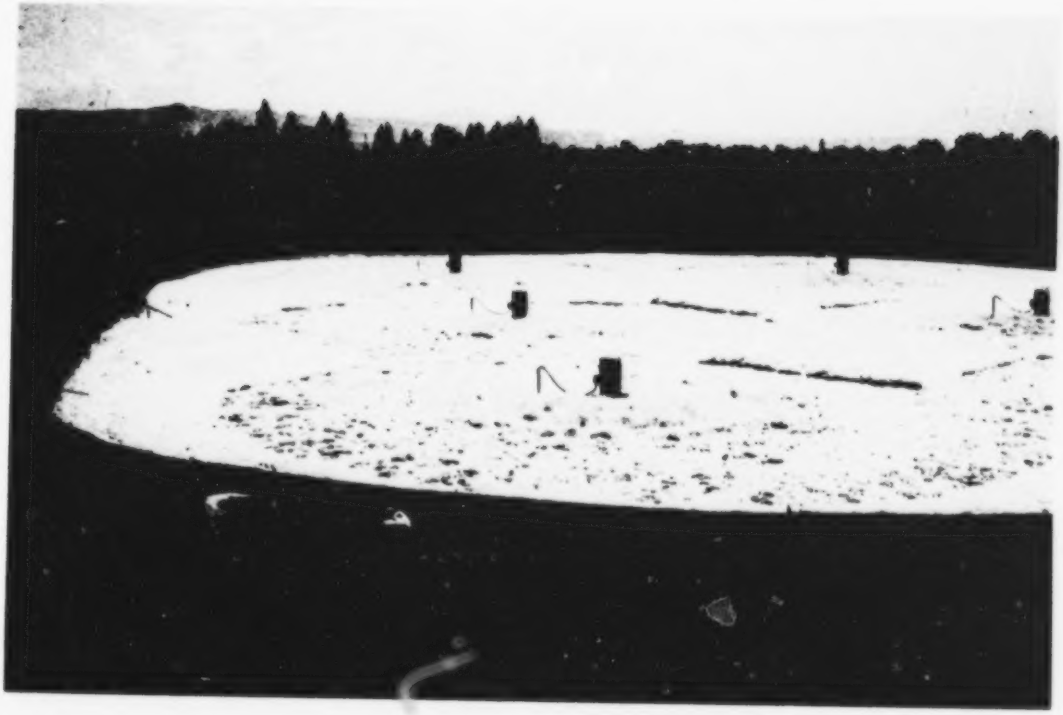

Figure 4. The R. T. French Company, Shelley, Idaho

AERATION BASIN 2

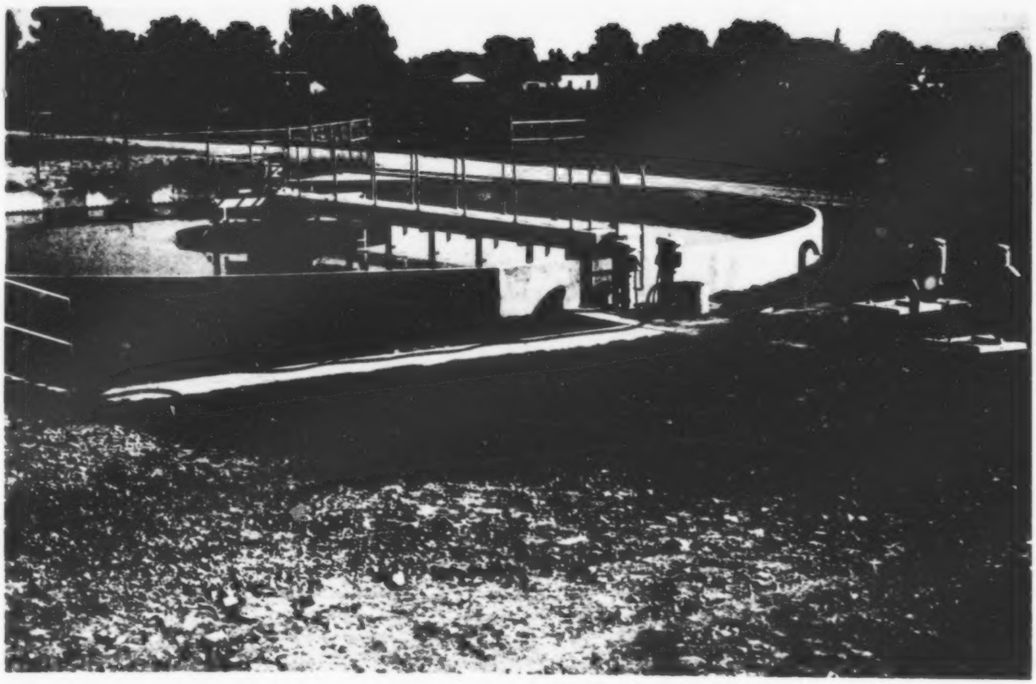

Figure 5. The R. T. French Company, Shelley, Idaho

SECONDARY CLARIFIER

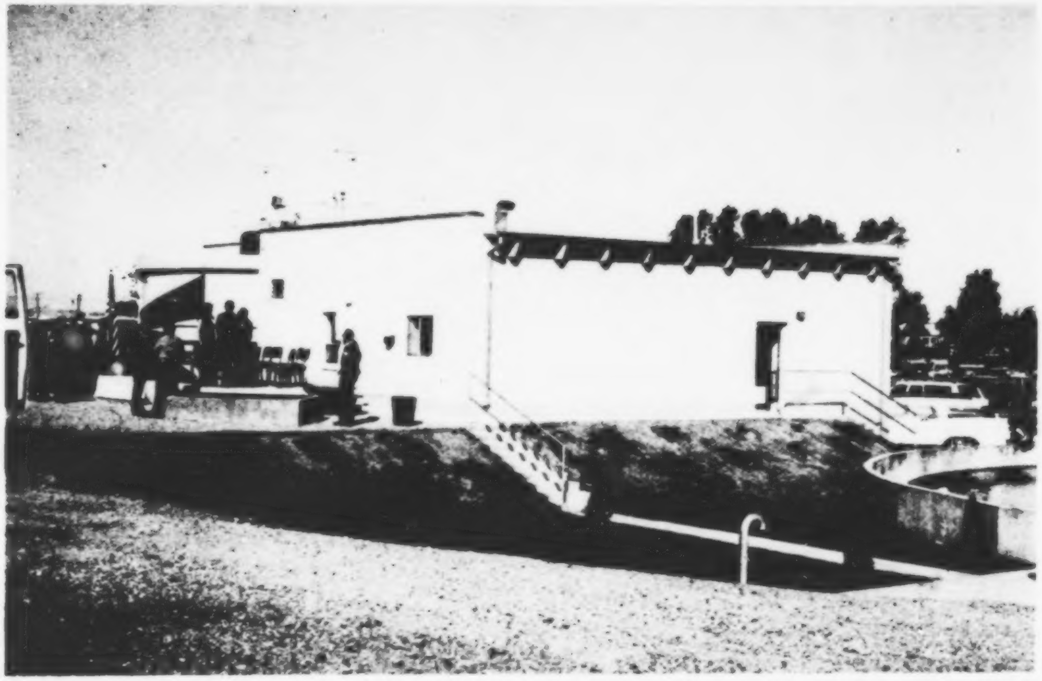

Figure 6. The R. T. French Company, Shelley, Idaho
CONTROL BUILDING

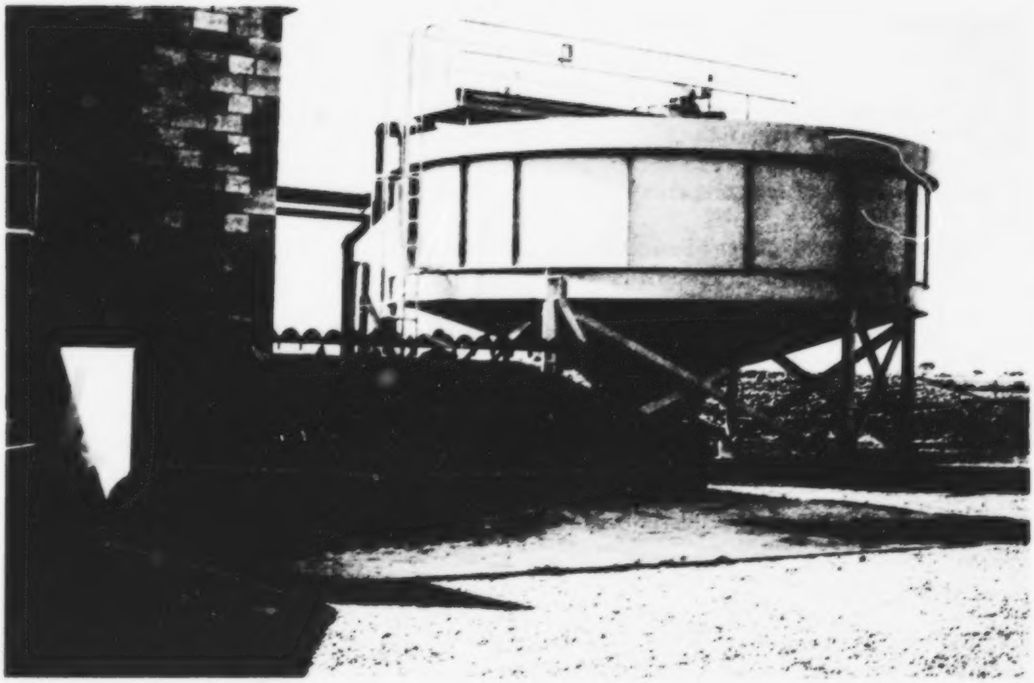

Figure 7. The R. T. French Company, Shelley, Idaho
CLARIFIER - THICKENER

Numerous mechanical problems have hindered plant performance; however, three months of effective operation has been achieved. The operating data from these three months of experience have been analyzed in greater detail than the other reported data.

Activated Sludge System - Figure 8 is a plot of the best fit curve of the frequency distribution of BOD loading to the activated sludge system on arithmetic-probability paper. The probability shown on this and following figures is the percent of measurement equal to or less than, the stated class mean of the measured item. Figure 8 shows that about 50 percent of the time the BOD loading to the activated sludge system was equal to, or greater than, the plant design load of 14,100 lb BOD/day; while 25 percent of the time, the BOD loading was equal to, or less than, 10,600 lb BOD/day.

Figure 9 shows that about 40 percent of the time the D.O. (dissolved oxygen) in Basin 1 was less than 1.0 mg/l, which is often thought to be a minimum level to avoid limiting biological activity. Figure 10 shows that Basin 2 was also operated at a D.O. of less than 1.0 about 40 percent of the time. Low basin D.O. was associated with mechanical aerator problems.

Figure 11 shows that about 23 percent of the time, Basin 1 temperature was equal to or below, 50°F (10°C), which is reported to be low enough for filamentous bacteria to become competitive. Figure 12 shows that a temperature below 50°F occurred about 18 percent of the time. Low basin temperature occurred at long aeration times and low air temperatures.

Figure 13 shows that about 25 percent of the time, Basin 1 pH was equal to, or above, 8.0, which is the top of the normal operating range for an activated sludge system. This occurred in Basin 2 about 35 percent (Figure 14) of the time, but neither basin appeared to be affected by the high pH.

CO_2 production in the aeration basins during organic material breakdown buffered the high alkalinity in the influent and resulted in a pH drop. This is illustrated on Figure 15. The average influent pH was 9.3 and the average basin pH was 7.8. Many of the high basin pH levels were associated with low organic removals, which resulted from mechanical aerator problems.

The average BOD loading (lb/1000 cu ft/day) and BOD removals (percent) are shown on Figure 16. The various operating phases are also shown on Figure 16. BOD reductions decreased during period of sludge bulking. Sludge bulking was associated with mechanical aerator failures, which lowered the available D.O. in the aeration basins below desirable levels.

Analysis of three periods of operation, each about one month long with the plant operating as a return sludge activated sludge system,

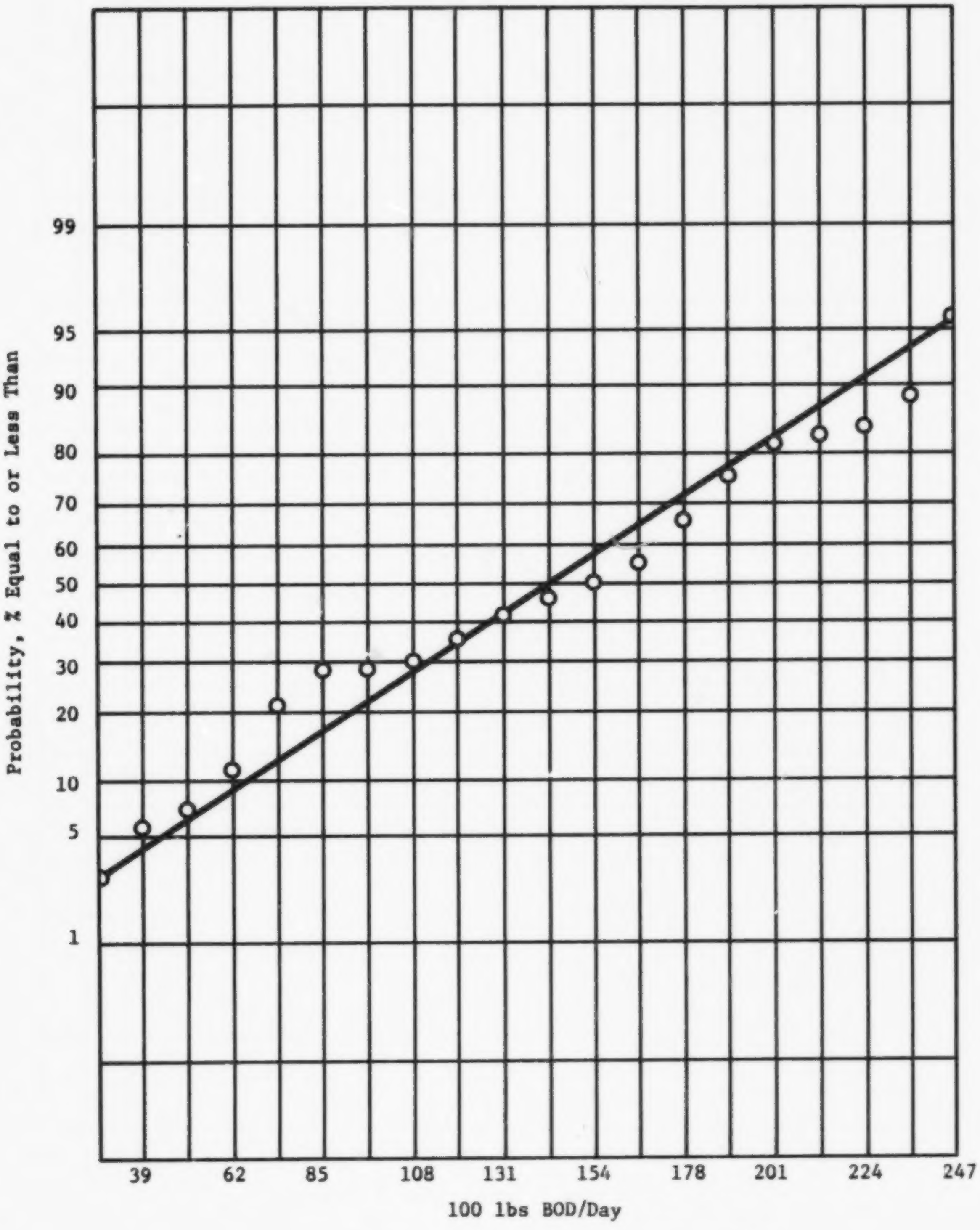

Figure 8. PROBABILITY OF PLANT LOADING

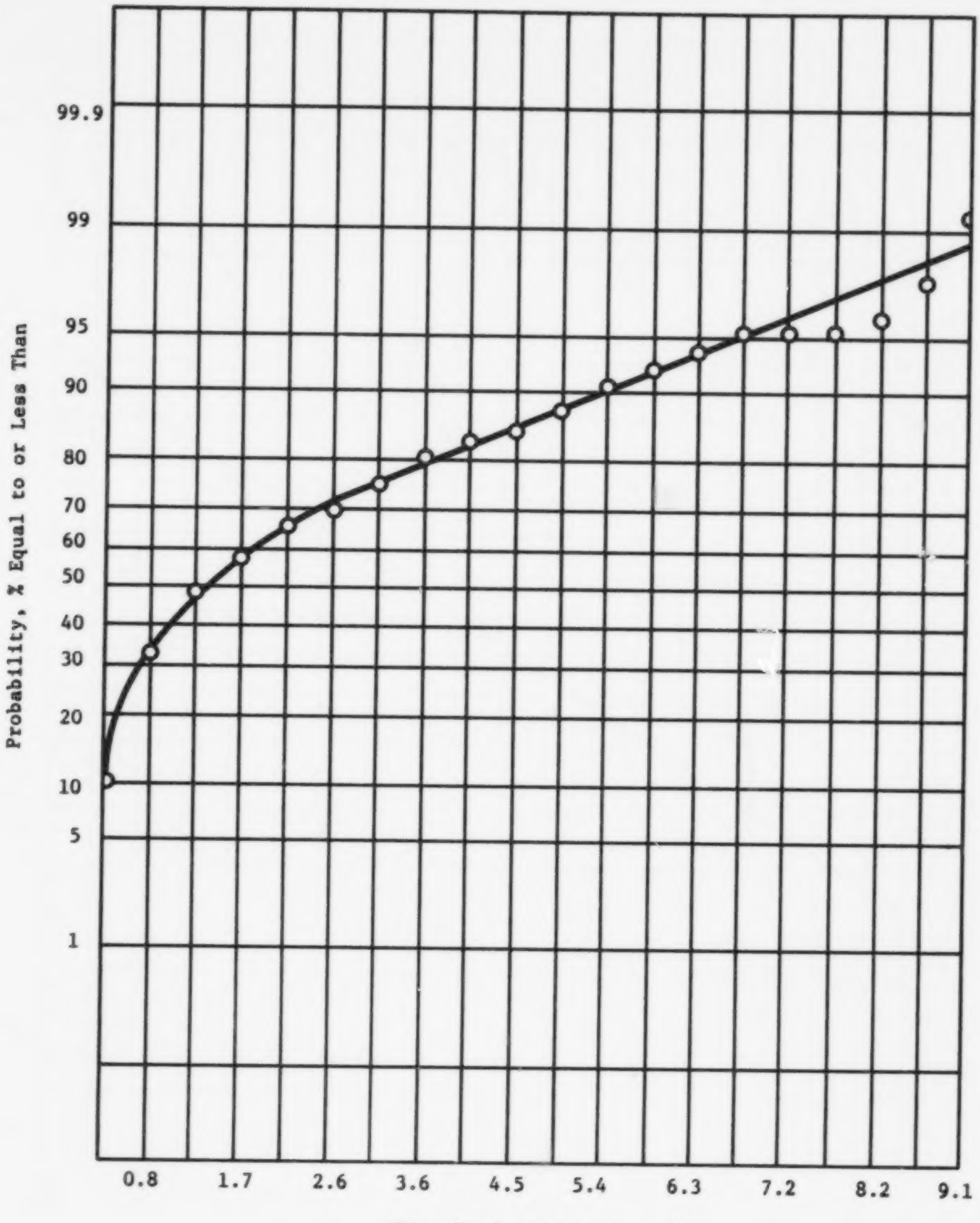

Figure 9. PROBABILITY OF BASIN 1 D.O.

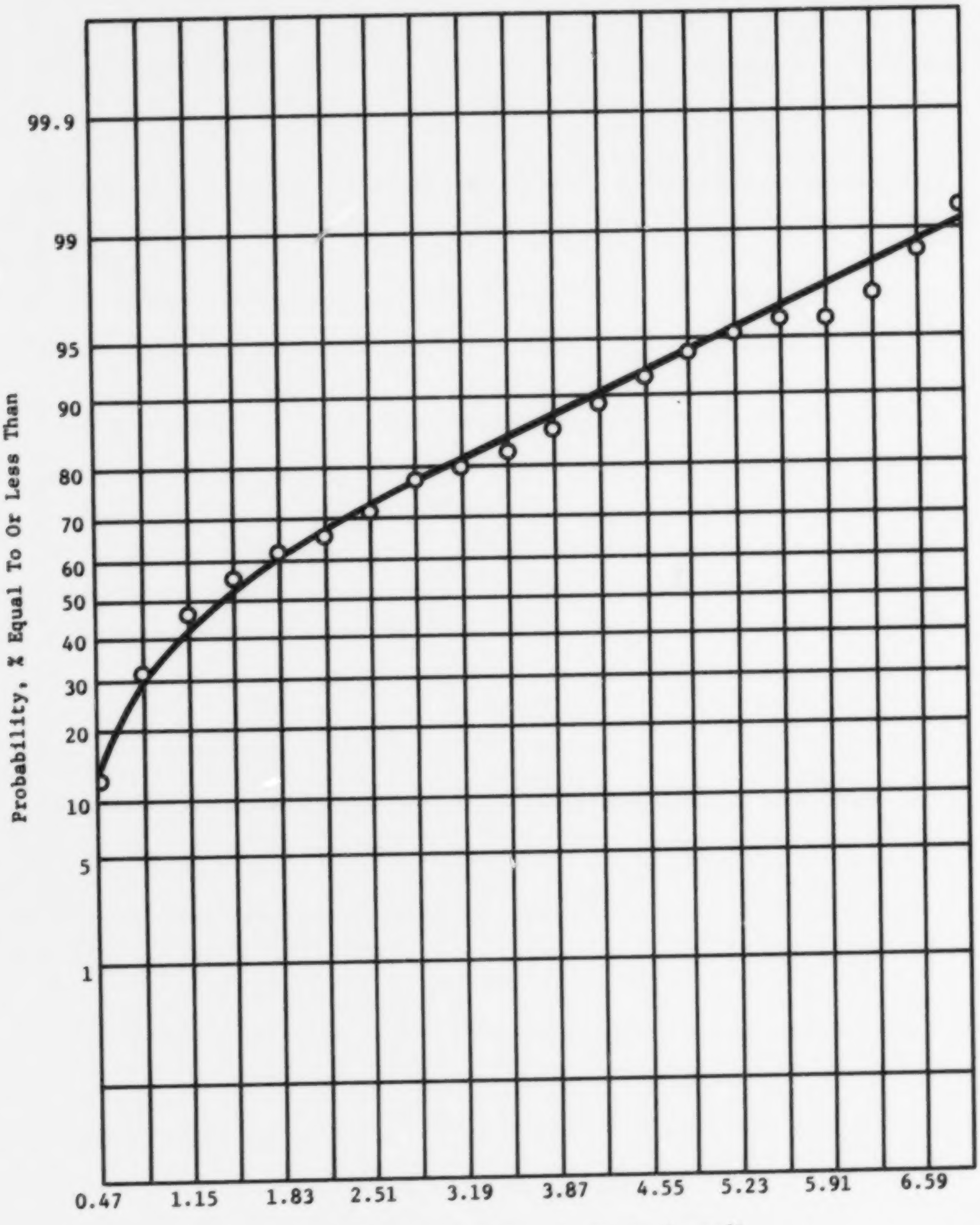

Figure 10. PROBABILITY OF BASIN 2 D.O.

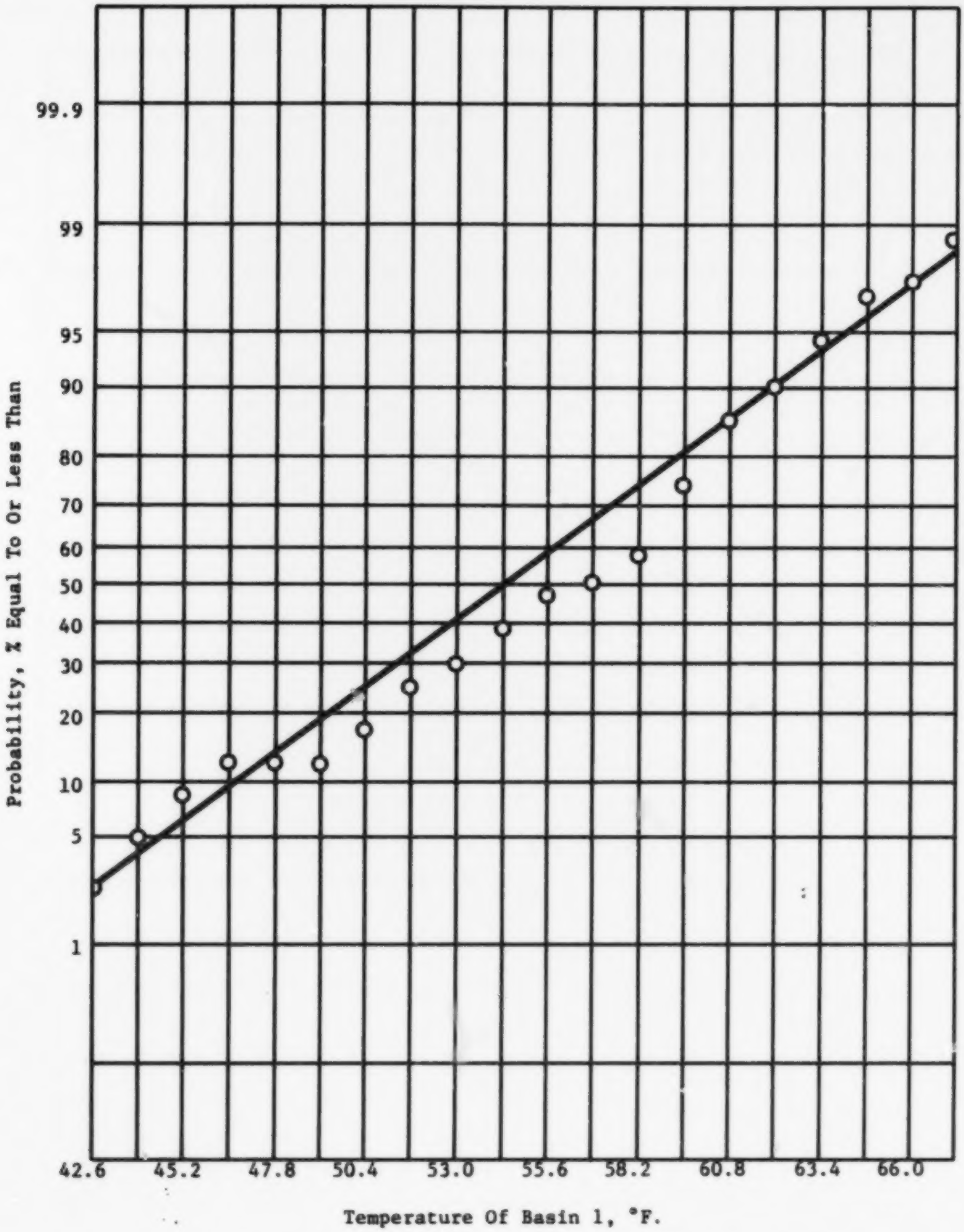

Figure 11. PROBABILITY OF BASIN 1 TEMPERATURE

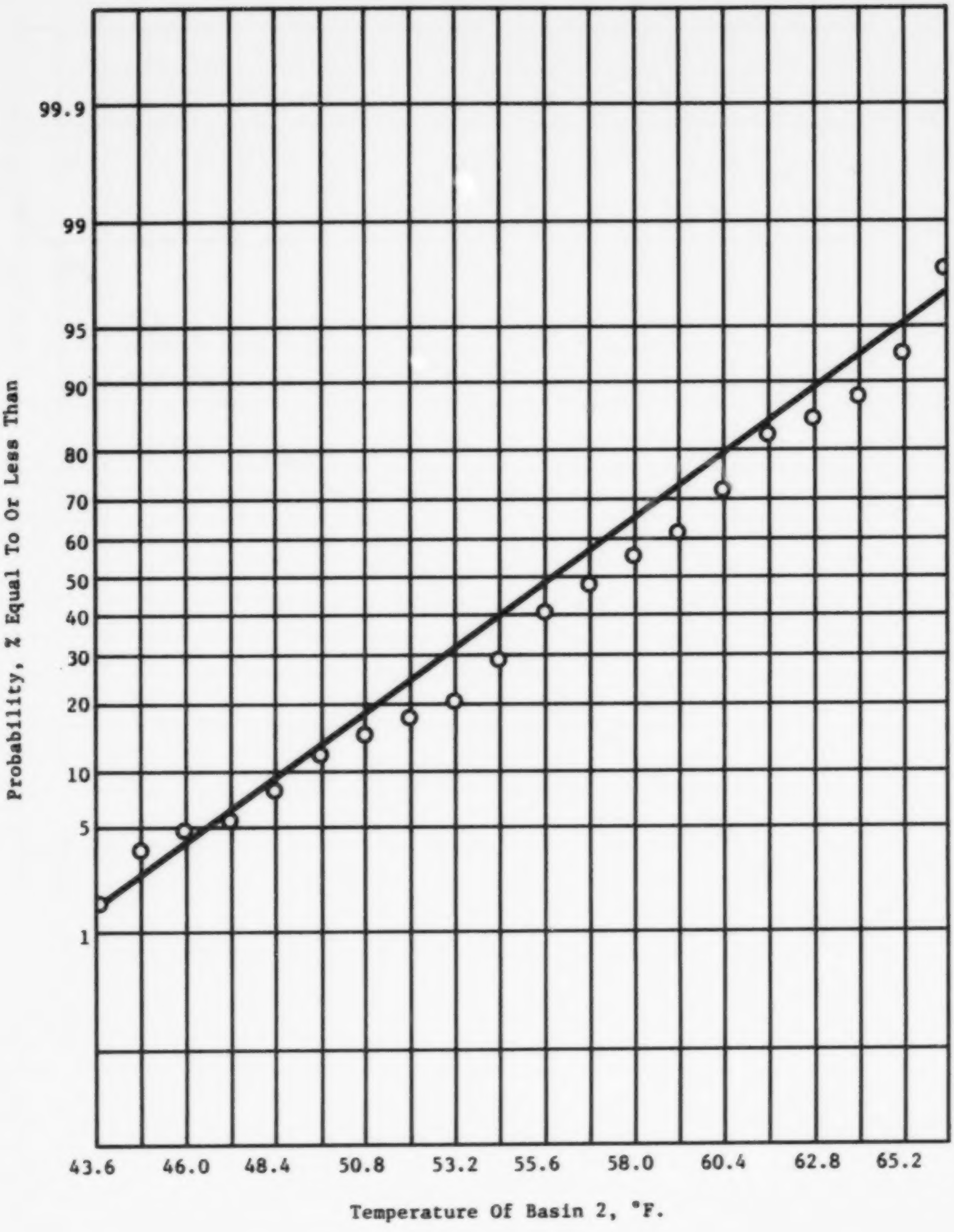

Figure 12. PROBABILITY OF BASIN 2 TEMPERATURE

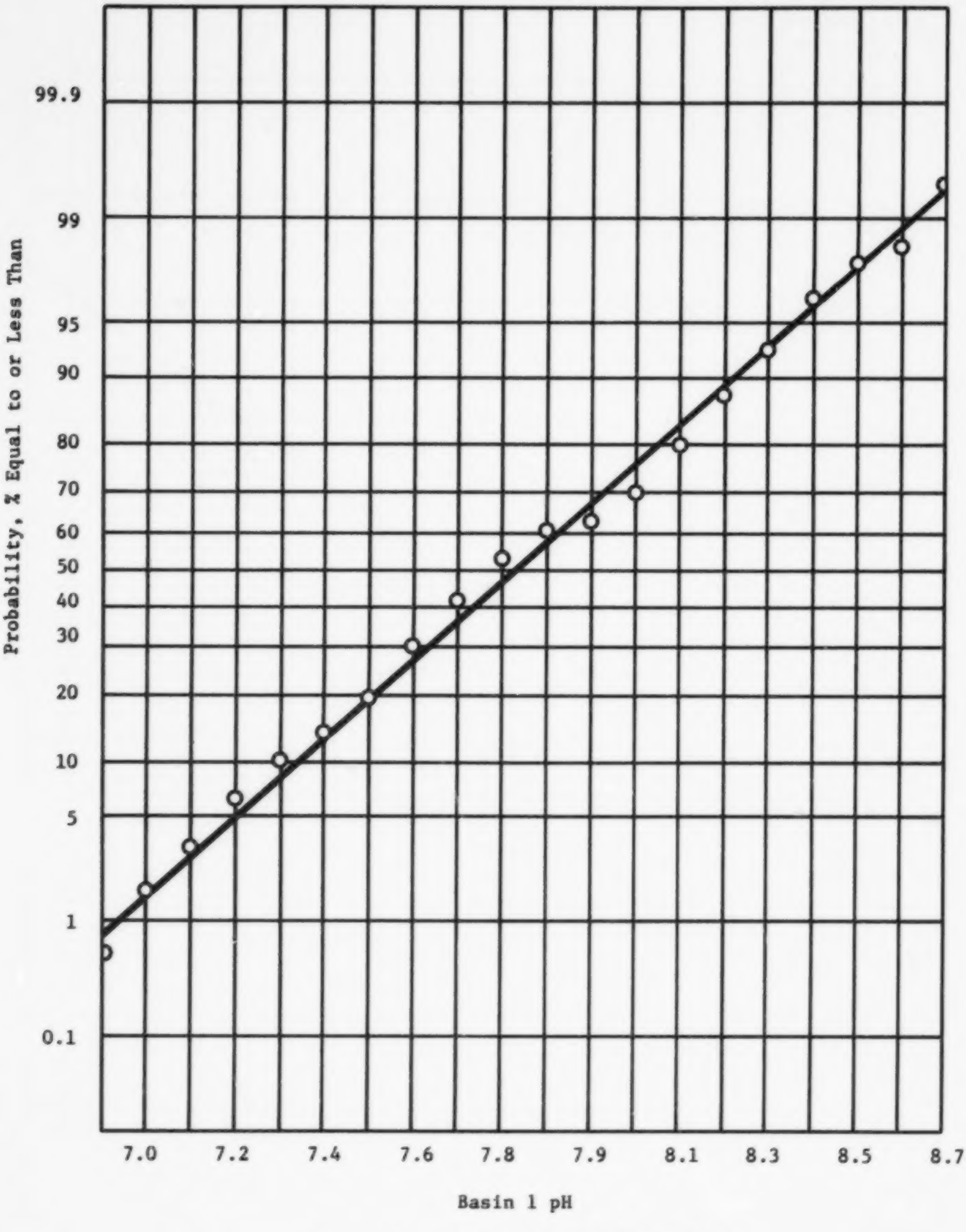

Figure 13. PROBABILITY OF BASIN 1 pH

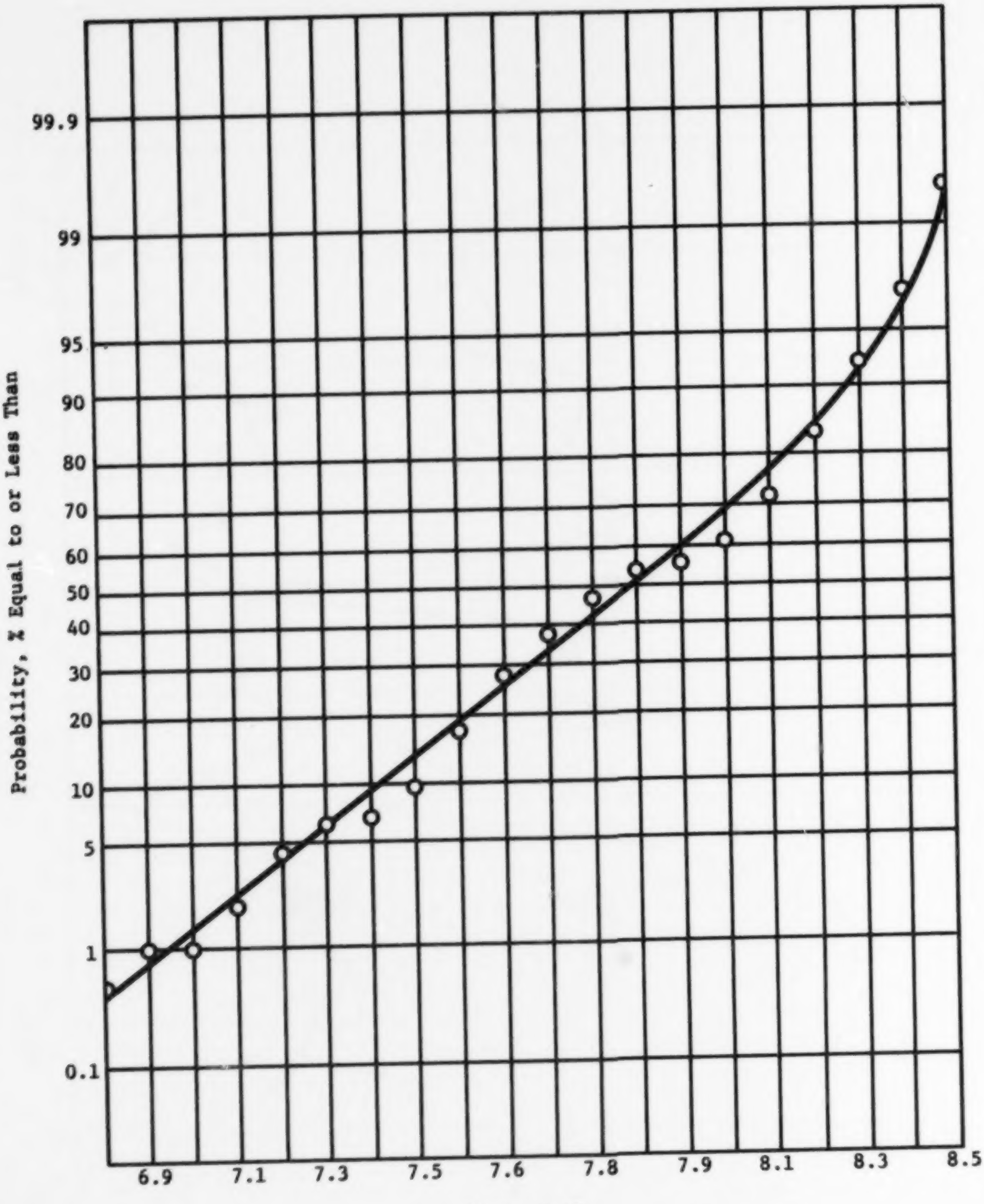

Figure 14. PROBABILITY OF BASIN 2 pH

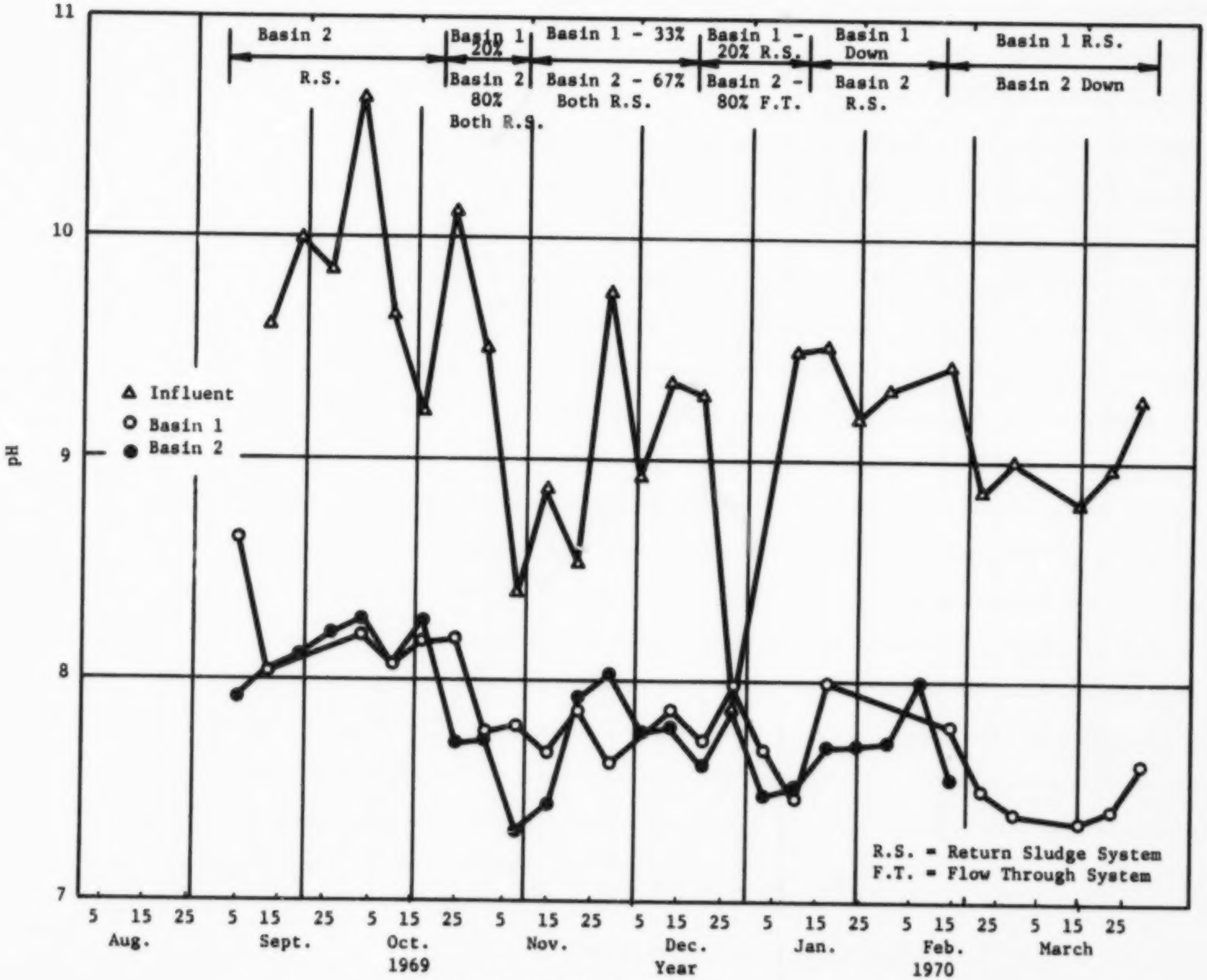

Figure 15. PLANT pH VS TIME

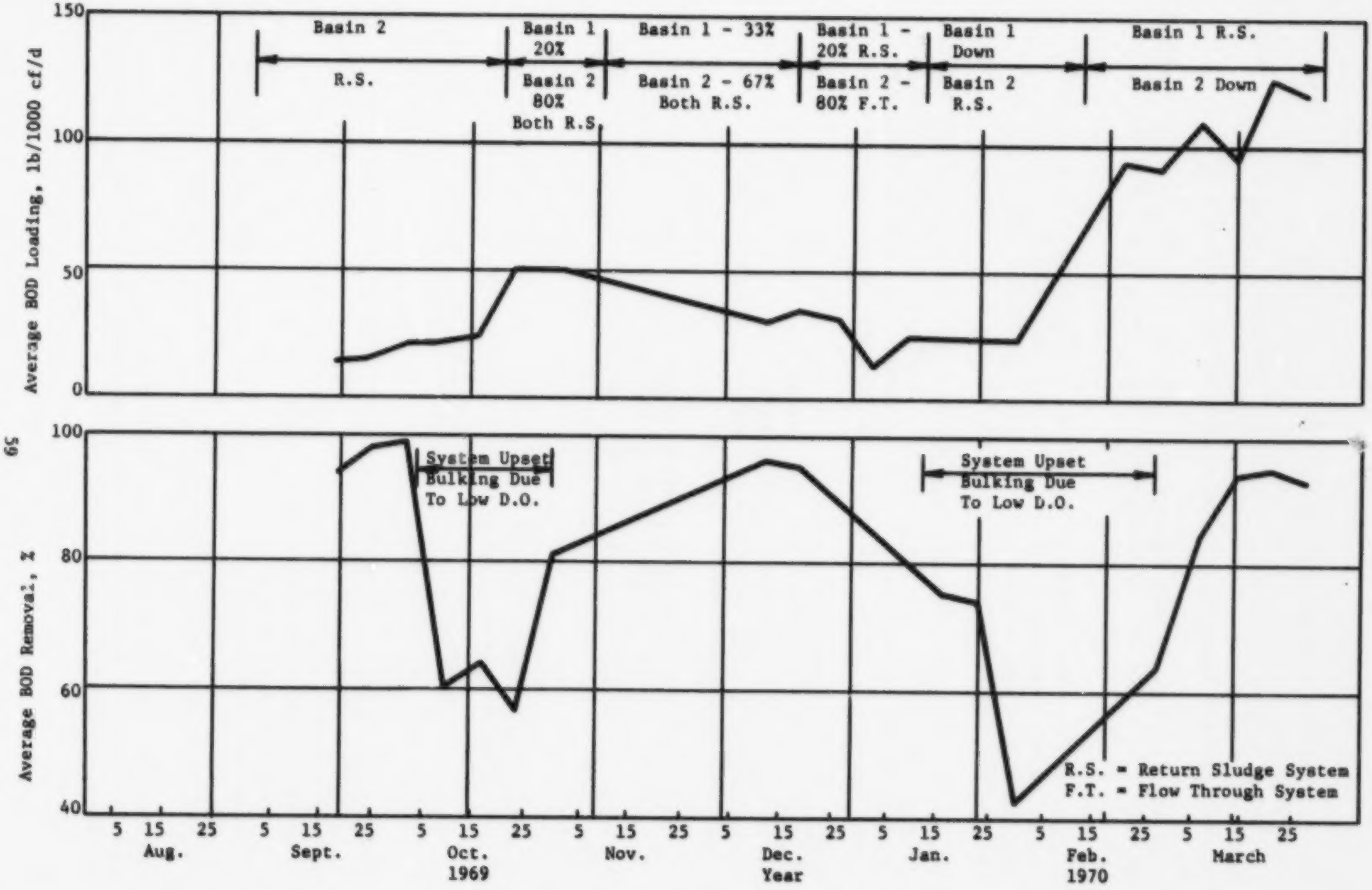

Figure 16. BOD LOADING AND REMOVAL VS TIME

has provided us with several operating relationships. These relationships are described below and are based on average weekly data. The three periods of operation are: September 14 - October 4 - November 23 - December 20, and March 1 - March 31. The referenced figures include least-square curves fit to the plotted data.

A relationship developed between effluent BOD and effluent TSS is shown on Figure 17. The relationship shows the need for good solids removal in the secondary clarifier.

Figure 18 shows the effect of MLSS (mixed liquor suspended solids) levels on effluent TSS. Increases in MLSS increased the solids loading to the secondary clarifier. It is believed that this was responsible for increases in effluent TSS.

The relationship between effluent soluble BOD and effluent TSS is shown on Figure 18. It indicates that some anaerobic metabolism may take place in the secondary clarifier when loaded with soluble BOD, resulting in gas production solids rising, and solids carryover.

Figure 19 is a probability plot of BOD removal for all reported data. During 50 percent of the time, the average BOD removal was equal to, or greater than, 83 percent. The average BOD removal for the entire period was 80 percent even though numerous mechanical problems limited operating efficiency much of the time.

The effect of BOD loading (lb BOD/lb MLVSS/day) on BOD removal is shown on Figure 20. Figure 21 shows the effect of this same BOD loading on effluent BOD. As the BOD loading increased, the effluent BOD appeared to increase, while the BOD removal remained above 94 percent.

Figure 22 shows the effect of BOD loading (lb BOD/1000 cu ft/day) on BOD removal. As the BOD loading increased, the BOD removal appeared to decrease slightly; however, additional testing will be required to verify this relationship. MLSS concentrations are not considered on this figure.

Clarifier-Thickener - Performance of the clarifier-thickener has varied considerably. Poor underflow pump performance has prevented frequent solids withdrawal and has reduced removal efficiencies. Waste activated sludge discharge to the clarifier-thickener has hindered silt settling and has reduced removal efficiencies. Coagulation studies have been conducted on mixed waste activated sludge and silt water, and coagulants may be added to the waste activated sludge in the future to increase removal efficiencies.

COD and BOD removal efficiencies of 80 percent have been obtained, and TSS removals have exceeded 90 percent with silt water alone flowing through the clarifier-thickener.

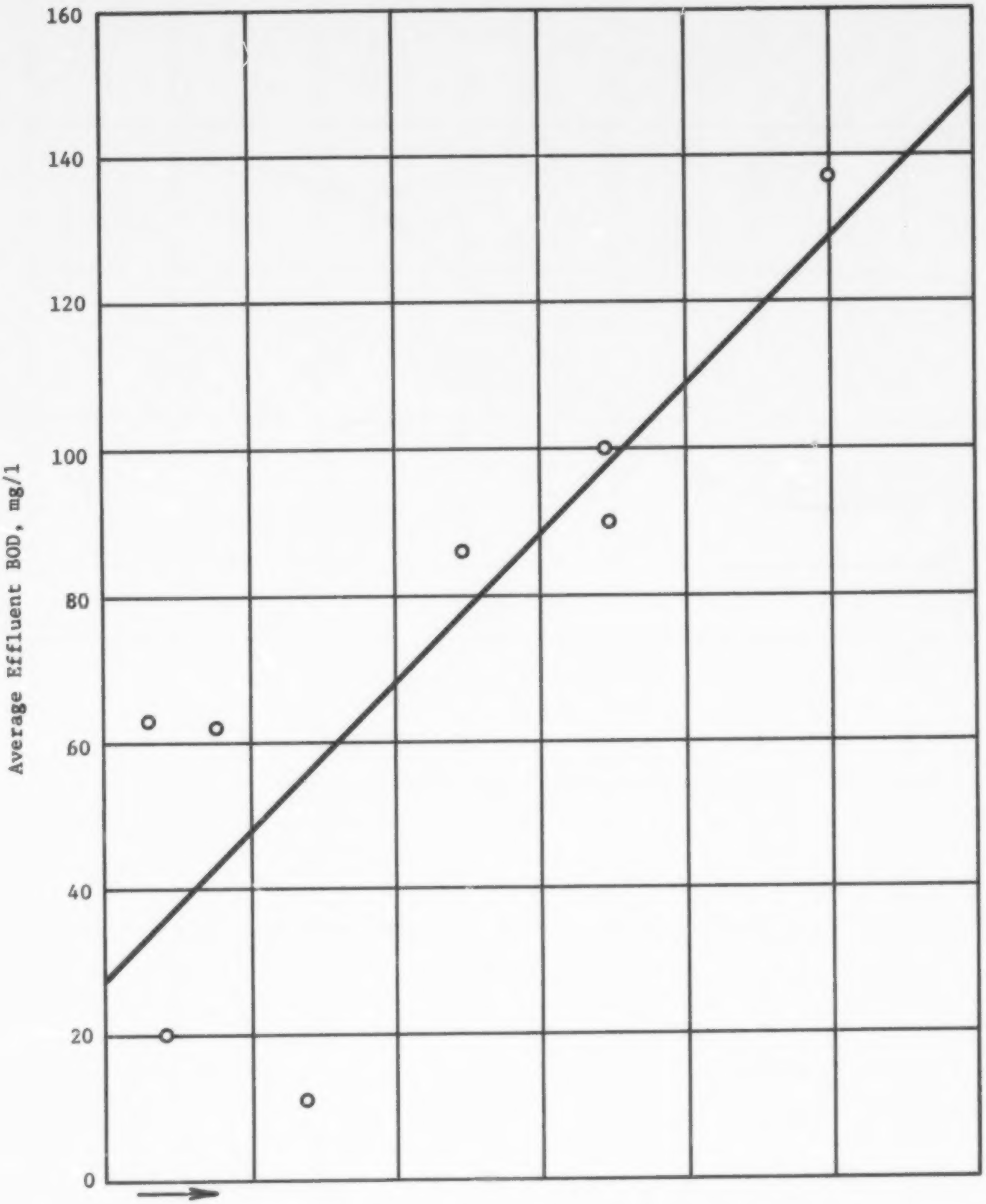

Figure 17. EFFLUENT BOD VS. EFFLUENT TSS

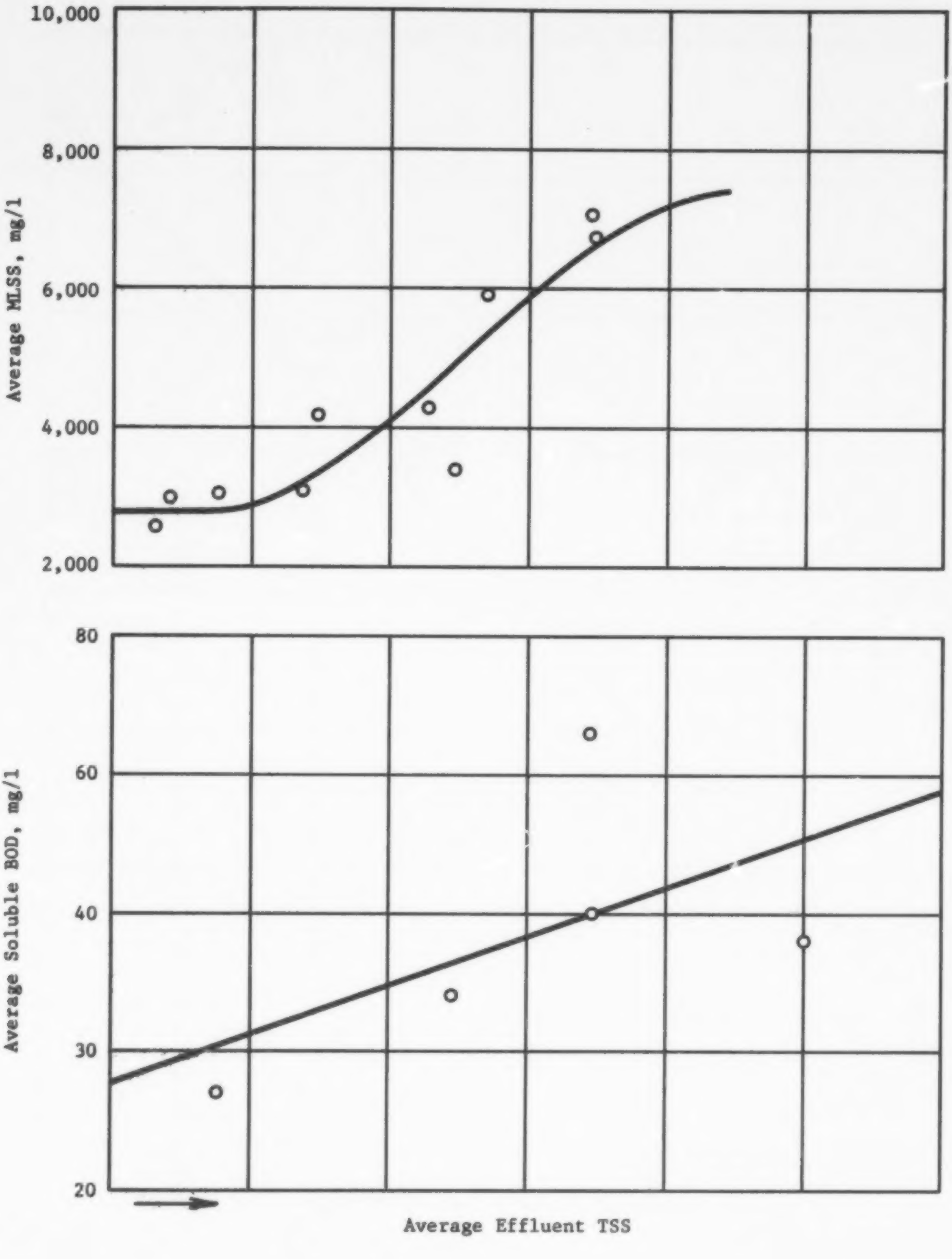

Figure 18. EFFLUENT SOLUBLE BOD AND MLSS VS. EFFLUENT TSS

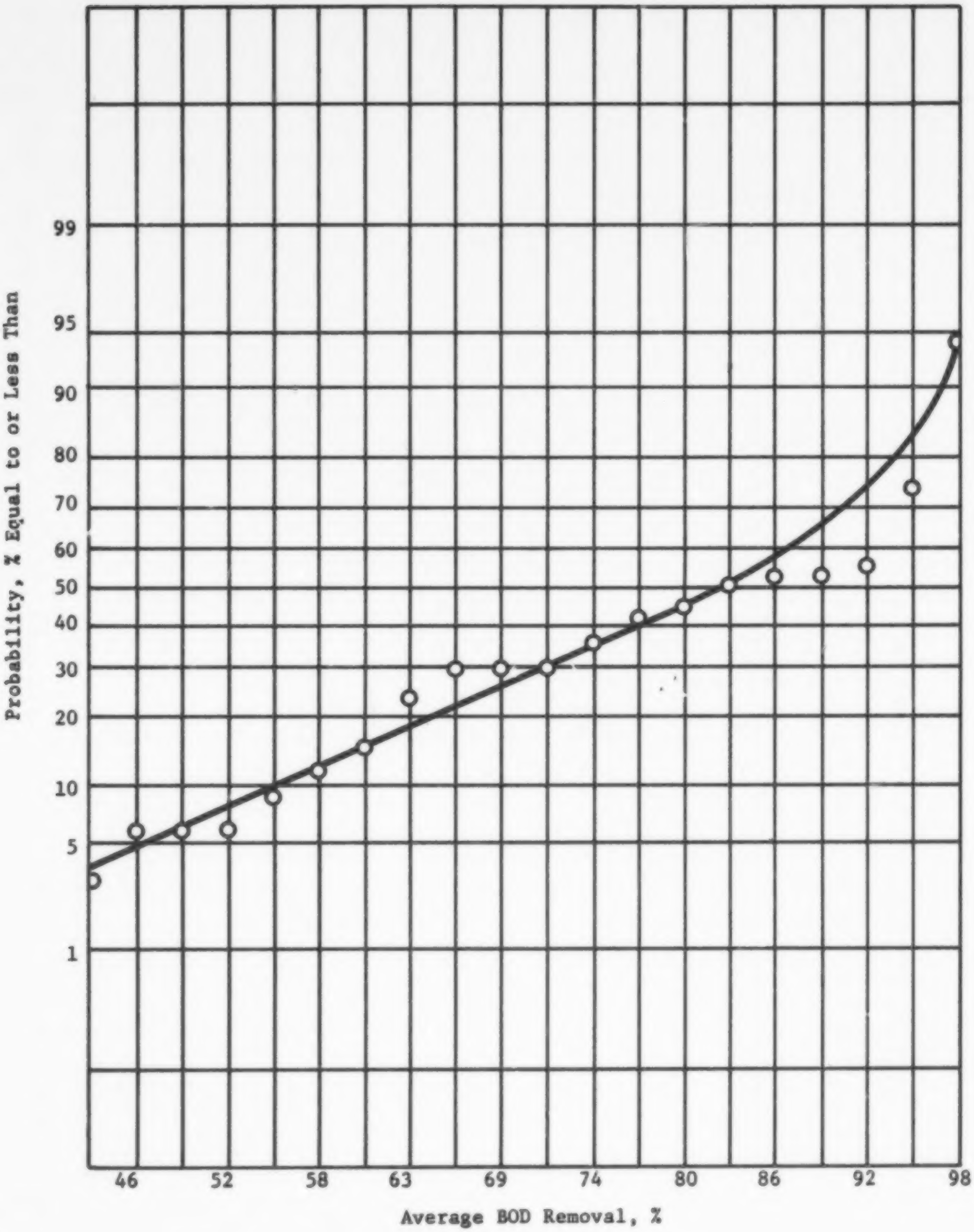

Figure 19. PROBABILITY OF BOD REMOVAL

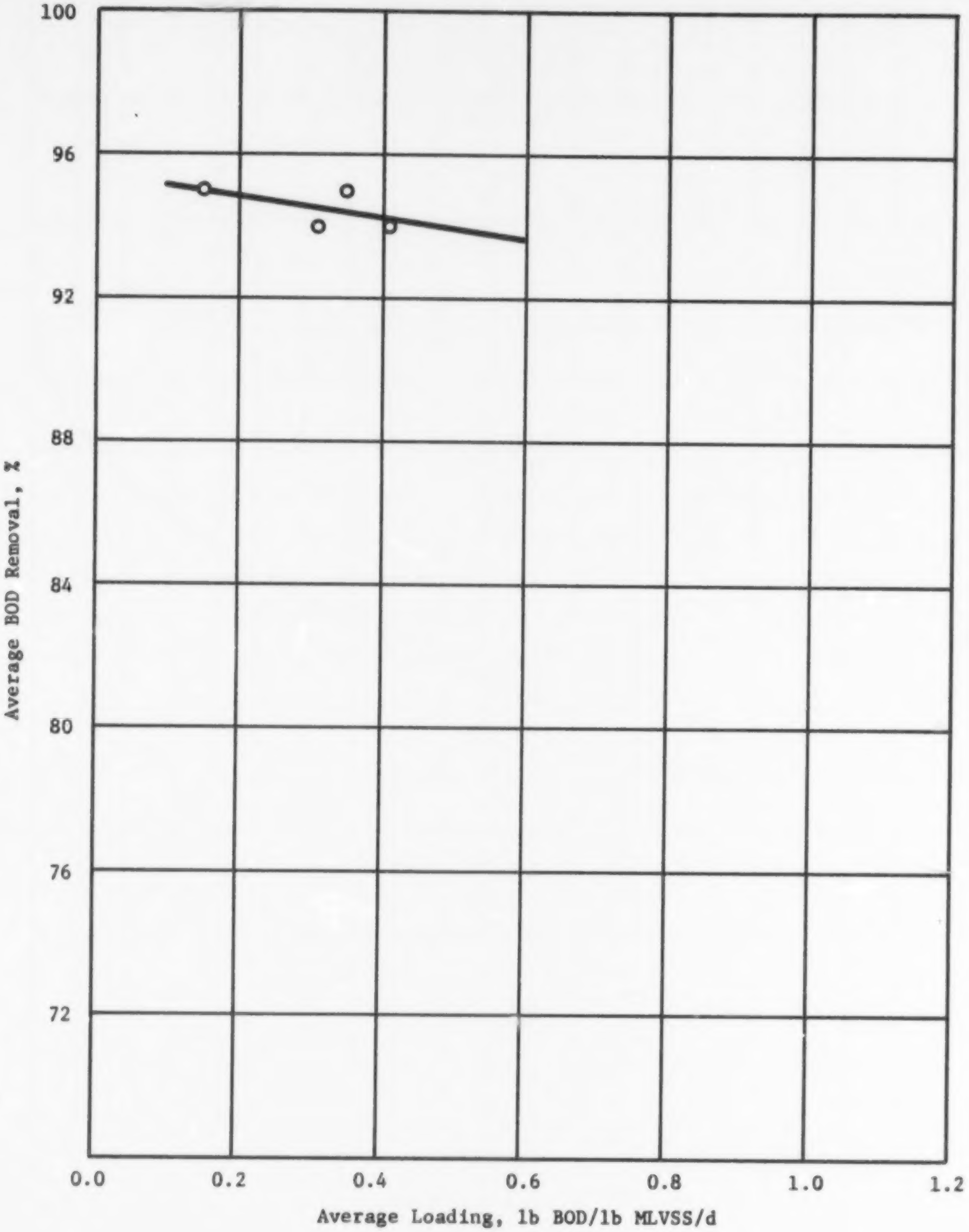

Figure 20. BOD REMOVAL VS. BOD LOADING

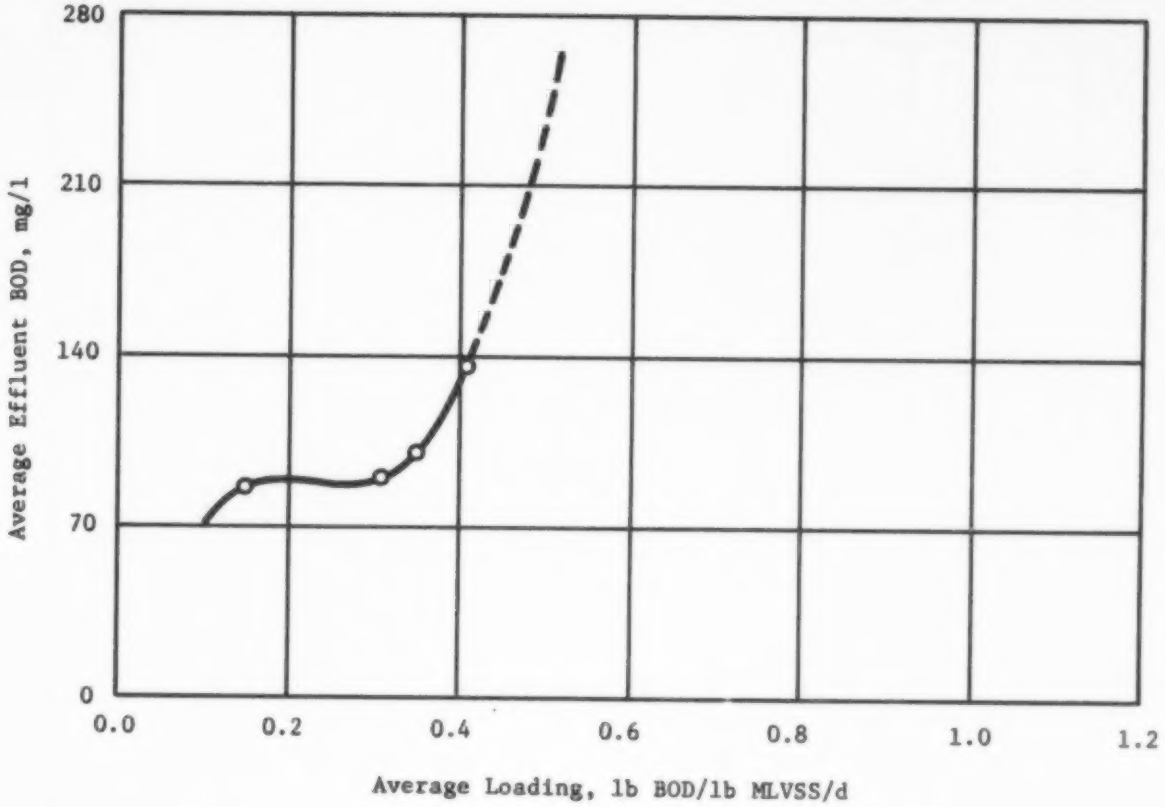

Figure 21. EFFLUENT BOD VS. BOD LOADING

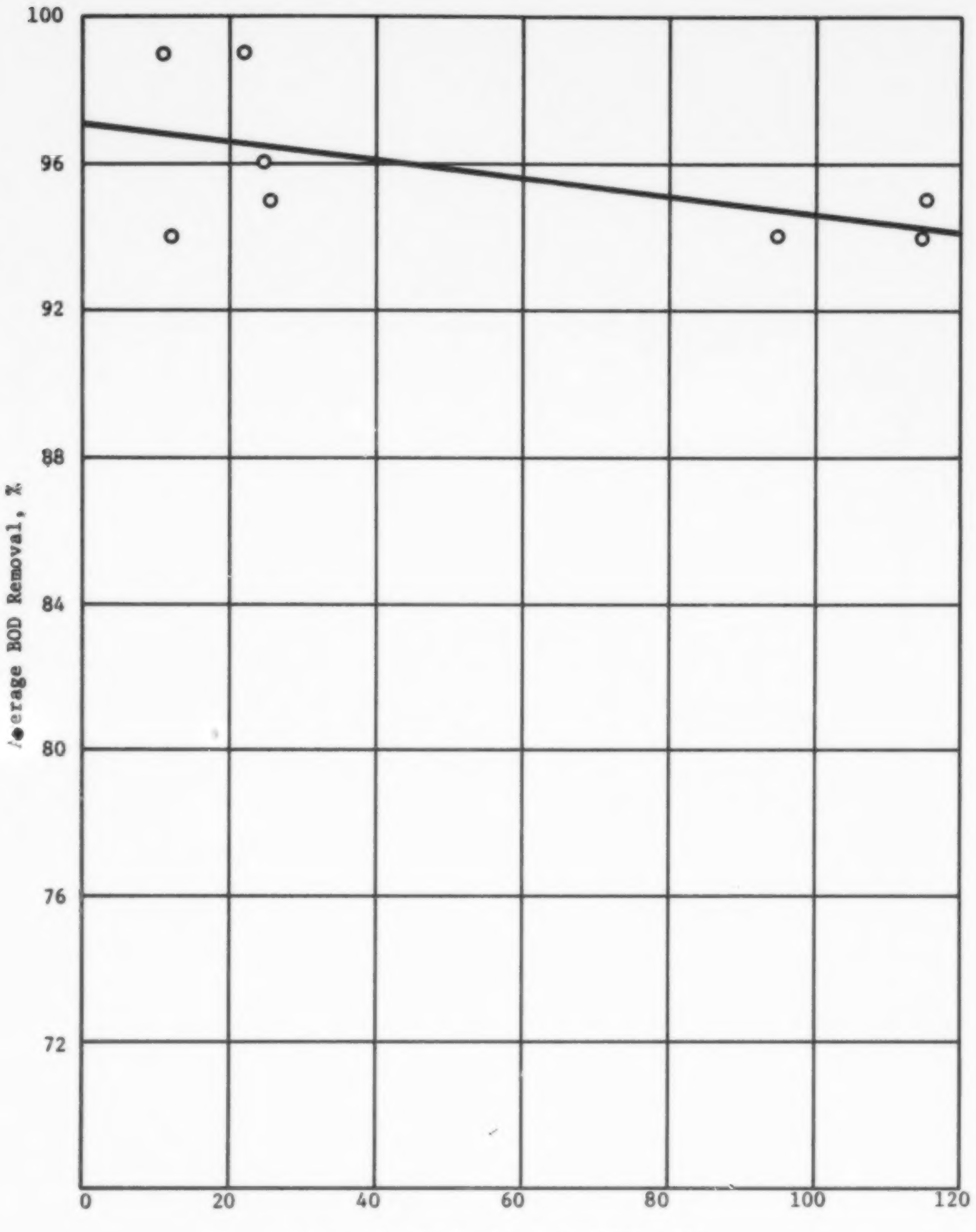

Figure 22. BOD REMOVAL VS. BOD LOADING

Vacuum Filtration - The solids concentration of the clarifier-thickener underflow averaged about 48 percent and the vacuum filter cake averaged 62 percent solids without coagulants. When an anionic polymer was added to the silt water entering the clarifier-thickener, the underflow solids increased to about 53 percent and the filter cake solids increased to about 72 percent. The addition of waste activated sludge directly to the vacuum filter has not been successful.

OPERATING PROBLEMS

Numerous mechanical problems have been encountered at the secondary waste treatment facility. As a result, problems have developed within the biological and physical processes. The mechanical and process problems encountered to date are discussed below, along with attempted solutions to these problems and their present status.

Mechanical Problems - The major mechanical problems, equipment modifications, and the present status of the problems are shown in Table 2.

Process Problems - Problems encountered in the activated sludge process have been primarily associated with sludge bulking. This has occurred several times and appears to be related to frequent aerator problems, with accompanying large fluctuations in D.O. levels and recycling of waste activated sludge through the clarifier-thickener. Increased D.O. levels, increased sludge wasting, and reduced influent BOD to basin MLVSS ratios have been used to eliminate the bulking sludge when it appears.

Foaming has occurred on the aeration basins at low MLSS levels, but has not been a problem at higher MLSS levels, while maintaining a high D.O.

Addition of an anionic polymer to the silt water, ahead of the clarifier-thickener, has improved the solids removal efficiency of the clarifier on silt water; however, the anionic polymer has no effect on waste activated sludge settleability. A cationic polymer may be added to the waste activated sludge in the future to aid settleability of the waste activated sludge-silt water mixture.

SUMMARY

Despite numerous mechanical problems, BOD removals of over 90 percent have been obtained for sustained periods of time, demonstrating the applicability of the activated sludge process for treating potato processing water.

High pH values of influent process water were buffered in the aeration basins and were not detrimental to treatment efficiencies.

Low temperatures have not caused failure of the activated sludge process. Data obtained do, however, demonstrate the need to consider temperature loss in system design. Temperature loss relationships will be developed in the final report.

TABLE 2

THE R.T. FRENCH COMPANY

MECHANICAL OPERATING PROBLEMS

MECHANICAL PROBLEMS	EQUIPMENT MODIFICATIONS	PRESENT STATUS OF PROBLEM
I AERATION BASINS		
A. HYPALON TOP LINING		
1. LINING WOULD NOT STAY BELOW WATER SURFACE.		
2. LINING CAUGHT IN WIND AND TORE IN SEVERAL PLACES.	LINING WAS REMOVED.	LINING WILL BE REPLACED WITH ROCK SURFACE
3. PIECES OF LINING CAUGHT IN AERATORS.		
B. PVC POND LINING		
1. LINING FAILED.		BASIN 2 LINING WAS REPLACED 13 APRIL
2. PARTS OF LINING BECAME BRITTLE.	PONDS WERE DRAINED AND LINING WAS REMOVED.	
3. PIECES OF LINING CAUGHT IN AERATORS.		BASIN 1 LINING WILL BE REPLACED IN EARLY MAY.
C. AERATORS		
1. AERATORS OVERDREW AMPERAGE.	HEIGHT OF DISCHARGE PORT WAS INCREASED.	SAME PROBLEMS REMAIN.
2. VARIATOR SYSTEMS BECAME INOPERABLE – WATER ENTERED MOTOR SEALS.	NEW VARIATOR MOTORS WERE INSTALLED AND VARIAC SYSTEM WAS MOVED UP TO MOTOR MODULE.	INOPERABLE.
3. ICE BUILT UP ON ELECTRIC LEADS AT AERATORS.	LENGTH OF ELECTRICAL LEAD STANDPIPE WAS SHORTENED.	OK
4. AERATOR MOTOR BEARINGS FAILED.	BEARINGS WERE REPLACED.	BEARINGS ARE STILL FAILING
5. AERATOR LEGS BROKE OFF.	LEGS WERE REPLACED.	FUTURE FAILURES EXPECTED
II SECONDARY CLARIFIER		
A. SLUDGE WITHDRAWL MECHANISM ROTATION WAS JERKY.	SEALS WERE ADJUSTED AND ADDITIONAL BRACING WAS INSTALLED.	OK
B. WASTE SLUDGE PUMP BECAME INOPERABLE.	PUMP WAS REPAIRED AND SAND WAS REMOVED FROM WASTE SLUDGE LINE.	OK
C. BEARINGS OF RECYCLE PUMPS.	REPLACED BEARINGS PUMP NO. 1	OK. REPLACE PUMP NO. 2 BEARING THIS SUMMER.
III CLARIFIER – THICKENER		
A. RAKES STOPPED TURNING.	THICKENER WAS DRAINED AND SILT WAS REMOVED.	SILT MUST BE REMOVED FREQUENTLY. SCHEDULED FOR CORRECTION THIS SUMMER.
B. UNDERFLOW PUMP BROKE DOWN.	BUILT UP PUMP SUPPORTS AND REBUILT PUMP.	STILL HAVING TROUBLE PUMPING SOLIDS
IV VACUUM FILTER		
A. SLUDGE WOULD NOT COME OFF CLOTH MEDIA WITH RUBBER SCRAPERS.	REPLACED CLOTH MEDIA WITH STAINLESS STEEL AND REPLACED RUBBER SCRAPERS WITH PLASTIC SCRAPERS.	STAINLESS STEEL MEDIA IS WEARING.
B. CAKE STUCK TO MEDIA.	STARTED ADDING COAG. TO INCOMING SILT WATER.	OK
C. SCREW CONVEYOR HOUSING HAD NO ACCESS FOR CLEANING.	NEW U-SHAPED HOUSING WAS CONSTRUCTED.	NEW BELT CONVEYOR TO BE INSTALLED.
D. OPERATION WAS NOISY.	INSTALLED UNDERGROUND MUFFLER ON EXHAUSE PIPING.	OK OUTSIDE, BUT STILL NOISY INSIDE. ADDING INSULATION.
E. SCREW CONVEYOR DRIVE MOTOR BROKE DOWN.	MOTOR WAS REPAIRED.	OK
F. FILTER CAKE FROZE OUTSIDE BUILDING, BINDING AUGER.	WRAPPED HEAT TAPE AROUND CONVEYOR.	OK
G. FILTER FEED PORTS DID NOT ALLOW THICK UNDERFLOW TO PASS QUICKLY ENOUGH TO FILTER.	PORT SIZE WAS ENLARGED. TEE DISTRIBUTION PIPE WAS INSTALLED.	NO GOOD. STILL UNSATISFACTORY.
H. SCREW CONVEYOR HANGER BEARING AND STUBB SHAFT WORE EXCESSIVELY.	BEARING AND SHAFT WERE REPLACED SEVERAL TIMES AND BEARING LOCATION WAS MODIFIED.	NEW BELT CONVEYOR TO BE INSTALLED.
I. SCREW AUGER WAS BENT WHEN INSTALLED, RESULTING IN EXCESSIVE RUBBING AND WEAR ON AUGER HOUSING.	AUGER WAS REMOVED AND STRAIGHTENED.	
V MISCELLANEOUS EQUIPMENT		
A. BEARINGS OF INFLUENT PUMPS FAILED.	REPLACED BEARINGS.	OK
B. SUMP PUMP BEARINGS FAILED.	REPLACED WITH BALL BEARINGS.	OK

Silt water can readily be concentrated in a clarifier-thickener and dewatered with a vacuum filter. Addition of waste activated sludge to the clarifier-thickener decreased removal efficiencies, but chemical coagulants can be added which may reduce this problem.

Operation of the clarifier-thickener, vacuum filter, and solids conveying system has demonstrated the need for special design for potato processing wastes.

USE OF FUNGI IMPERFECTI IN WASTE CONTROL

by

Brooks D. Church and Harold A. Nash*

Studies have been conducted by North Star Research and Development Institute under a grant by the Federal Water Quality Administration and four participating food processing companies (Green Giant Company, General Mills, Inc., Central Soya Company, Inc. and Ralston-Purina Company) to investigate the digestion of corn and soy waste streams by fungi.

The rationale for the use of fungi in treating waste streams from food processing plants has been that of incorporating the dissolved and suspended nutrients into a macroscopic organism which can be filtered out readily. A second hope is that the fungal mycelium will have utility as a feed so that its sale will help defray treatment costs. In order for a process using fungi to meet these objectives it was considered necessary that it have the following characteristics:

1. The fungi must be capable of reducing BOD to low levels.

2. The waste digestion cycle should be a short one.

3. The fungi must be capable of maintaining themselves as the dominant organism in spite of the nonsterile nature of the waste streams and environmental variations e.g., temperature, pH, feed rate, nutrient level, etc.

4. The mycelium must be readily recovered from the digestion mixture.

5. If the mycelium is to be an acceptable feed capable of commanding a continuing place in the feed market, it must be nontoxic, of high protein content, digestible, and bland in character.

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*North Star Research and Development Institute, 3100 38th Avenue South, Minneapolis, Minnesota 55406.

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METHODS AND MATERIALS

Waste streams used in the investigations were obtained from corn canning operations and from manufacture of soy protein. Waste stream supplies were drawn, immediately frozen and kept in the frozen state until just before use. Waste streams from soy protein manufacture included one in which the protein had been precipitated by hydrochloric acid and one in which the acid used was sulfur dioxide.

Our general approach was that of selecting cultures with promising capabilities on the corn and soy waste streams in shake flask cultures and testing them in detail in a continuous configuration. The continuous culture apparatus is shown diagramatically in Figure 1. The fermentation vessel was a topless 20-liter polyethylene jug inverted over a 300 mm glass funnel. The feed solution was stored in a cold room and pumped into the fermentation continuously. This produced a continuous effluent which was passed through a nylon mesh to remove fungal mycelium. Aeration and stirring of the fermentation was accomplished by the air fed into the system through stone spargers. When addition of nitrogen or phosphate was required, the additions were made to the feed reservoir. Sulfuric acid additions were similarly made to the feed reservoir in amounts shown by previous experience to yield operating pH values in the range desired. Additional amounts were added occasionally when the pH drifted upwards. No attempts were made to maintain sterile operating conditions, and the feed was nonsterile.

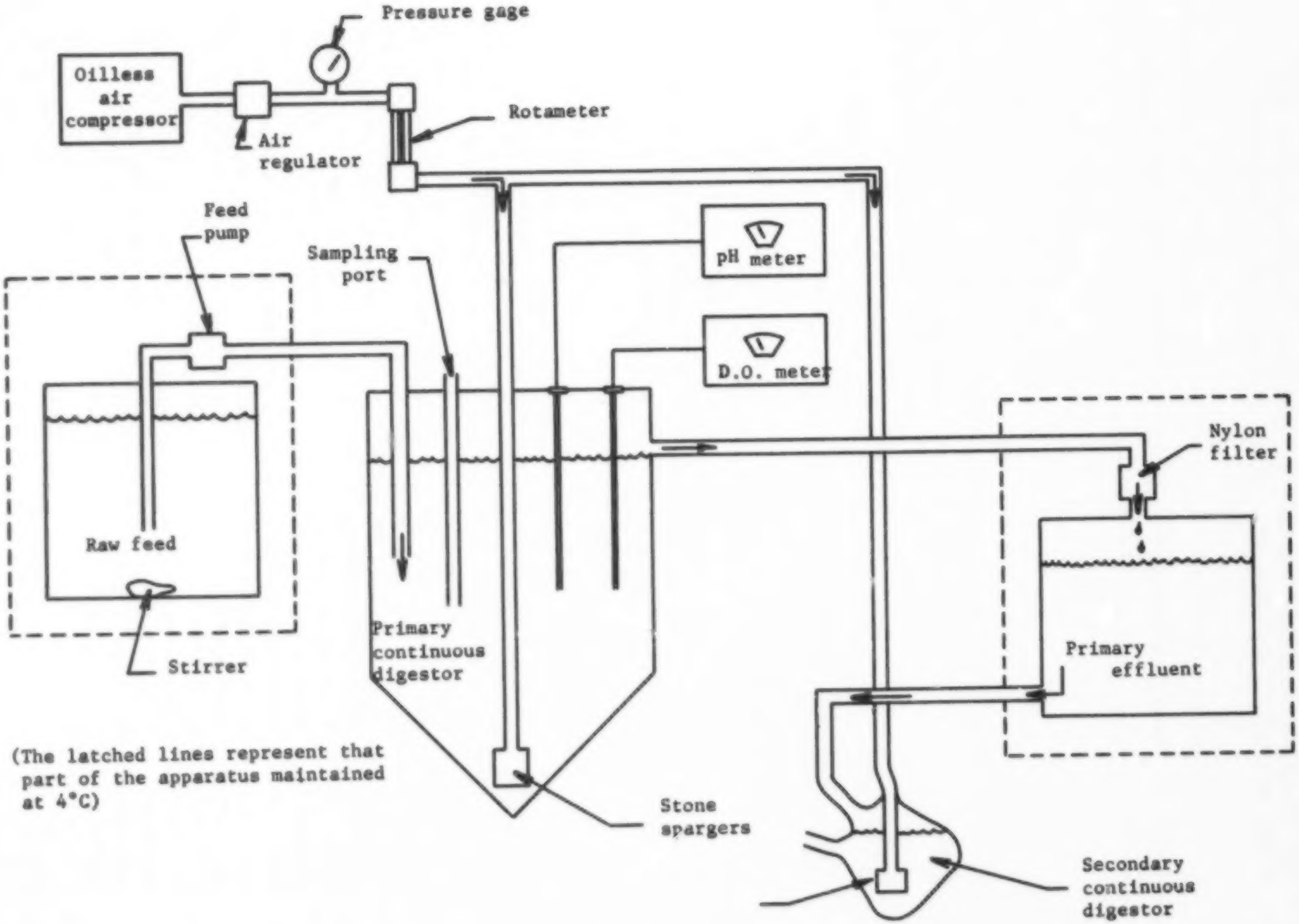
Measurements made in monitoring the fermentation included regular measures of influent and effluent COD, occasional measures of BOD_5, regular microscopic examination, regular measures of pH, temperature, and mycelial mass. Phosphate determinations were made by the Fiske and Subbarow method, protein determinations by the Lowry method, carbohydrate measures by the phenol sulfuric acid method, and nitrogen determinations by the micro-Kjeldahl method.

RESULTS

Strain Selection

Forty-eight strains from eighteen genera of fungi obtained from Dr. Gray at Southern Illinois University, Dr. Emmons at Natick Laboratories, and Dr. Hesseltine at Northern Regional Laboratories of the United States Department of Agriculture were screened for their ability to grow rapidly, reduce BOD effectively, and efficiently convert waste stream materials into mycelium of high protein content.

These fungal candidates were grown in sterile and nonsterile corn and soy waste in Erlenmeyer flasks on a rotary shake rack at various pH's, temperatures, and with or without the addition of certain inorganic salts.


Pressure gage
Oilless air compressor
Air regulator
Rotameter
Feed pump
Sampling port
pH meter
D.O. meter
Raw feed
Stirrer
Primary continuous digestor
Stone spargers
Nylon filter
Primary effluent
Secondary continuous digestor

(The latched lines represent that part of the apparatus maintained at 4°C)

Figure 1. FERMENTOR APPARATUS FOR CONTINUOUS DIGESTION OF CORN AND SOY WASTE BY FUNGI

The fungal strains best meeting the criteria described above are shown in Table 1 together with their optimal growth conditions.

Table 1. Characteristics of Corn and Soy Fungal Digestion Systems

	Substrate	
	Corn	Soy
Fungi	**Trichoderma viride* I-23	*Gliocladium deliquescens* I-31
Optimal pH	3.5	3.5
Optimal temperature °C	30	30
Additional supplements	Nitrogen Phosphate	None

*I numbers are William D. Gray's strain designation.

Continuous Culture - Corn

Continuous culture treatment of corn wastes with *Trichoderma viride* I-23 was highly successful. The operation of the fermentation over a 140-day period is shown in Figure 2 in terms of COD in the effluent solution after filtering out the mycelium on a nylon mesh. The COD of the feed was initially 3700 to 3900 mg/l and in the latter period of the run was 5200 mg/l. The feed rate was 15 to 18 ml/min, which corresponds to a turnover time of 17 to 20 hours. The temperature was in the range 25-28°C. The COD of the effluent was generally maintained at levels below 200 mg/l but with occasional escapes to higher levels. These escapes were associated with definite events in the feed of the fermentation. At points A and B, the feed line clogged, and the culture went into starvation with some lysis. At points C and D, the feed line valve stuck in the open position (feed was controlled by intermittent operation of a solenoid), and the fermentation was overwhelmed with fresh influent. In area E, excellent stability was achieved by decreasing the phosphate additions to a lower level. Our accumulated experience has been that feed interruptions of longer than 12 hours were likely to result in increased COD in the effluent.

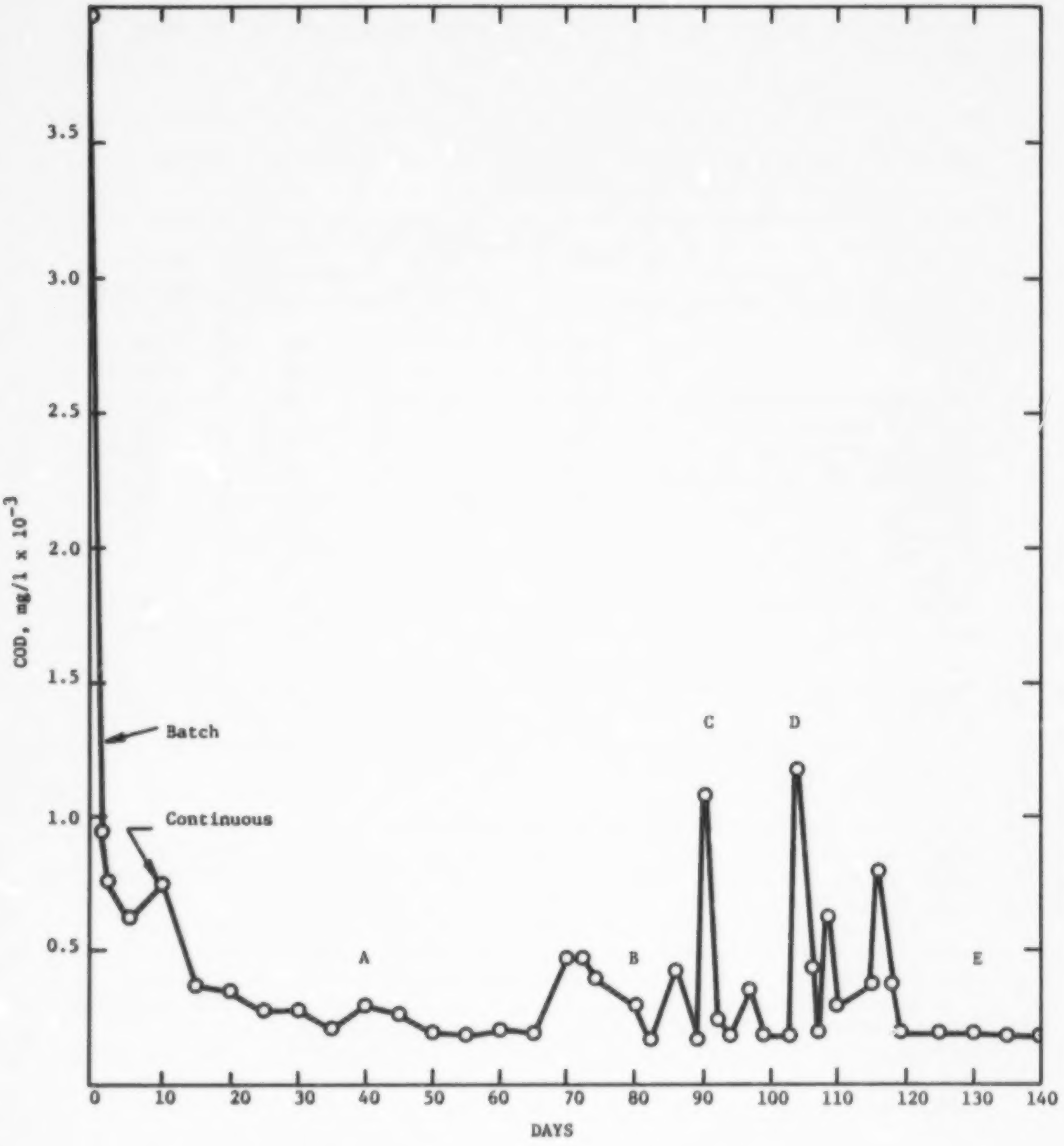


Figure 2. CONTINUOUS DIGESTION OF CORN WASTE BY *T*. *VIRIDE*

An analysis of fermentation behavior during period E is shown in Table 2. The removal of BOD_5 is seen to have been over 99 percent. Phosphate and nitrogen were removed to low levels. Sulfate was present in higher concentrations in the effluent than in the influent because of additions of sulfuric acid and ammonium sulfate. Even so, 48 percent of the total sulfate was removed in the mycelium. The mycelial dry weight was equivalent to about 55 percent of the BOD_5 consumed.

Table 2. Continuous Culture Digestion of Corn Wastes by a Strain of *Trichoderma viride*

Test	Milligrams per liter			Percent Reduction
	Feed	Feed Addition	Effluent	
COD	5200		196	96.2
BOD	3976		35	99.2
Carbohydrate (total)	3500		64	98.2
Protein (Folin)	200		7.5	96.0
Nitrogen (Kjeldahl)	96	22[a]	2.4	98.8
Phosphate (total soluble)	32	13[a]	0.15	99.6
Sulfate	120	280	210	48.0
Chloride	784		55	93.9
Mycelial weight	0		2200	
Solids in feed	4000			
Solids in effluent			760	81.0
Ash	980		510	52.0

[a] Ammonium sulfate added as nitrogen source to give mycelium of high protein content and NaH_2PO_4 was the form of phosphate addition. Values in table correspond to actual nitrogen and phosphate mg/l added.

Continuous Culture - Soy

Soy waste streams were of two types, depending on the acid used in reprecipitating soy protein. In one stream hydrochloric acid had been used and in the other, sulfur dioxide. Relatively little effort was devoted to the soy whey from hydrochloric acid precipitation of soy protein, and success was only moderate. Eighty to ninety percent reduction of COD was obtained, but difficulty was encountered in maintaining stable fermentations. Fermentations began well enough but soon deteriorated, and competing organisms appeared. The mycelium showed evidence of ageing and starvation, even though the COD of the effluent was above the levels we hoped to attain. Difficulty was also encountered with mycelium gathering at the top of the fermenter in bulky masses.

Since SO_2-soy whey was judged to be the more important problem commercially, the fermentation difficulties were pursued with this medium with the rationale that successful solutions for the SO_2-soy whey could be applied to the HCl-whey. Tolerance to SO_2 was low for many Fungi Imperfecti strains, but it proved possible to select strains of Aspergillus oryzae and Gliocladium deliquescens which would tolerate SO_2 levels as high as 700 mg/l. Repeated passage through media containing incrementally higher levels of SO_2 resulted in improved tolerance to SO_2. The fermentations destroyed SO_2. The strains which tolerated the highest SO_2 levels and would give good COD removal were selected for further study.

As in the case of HCl-soy whey, difficulty was encountered in maintaining a stable fermentation. After successful start-ups, cultures showed evidence of lysis, and yeast became prominent. Two expedients were found successful in preventing such culture deterioration. Both were based on the premise that the deterioration resulted from starvation of the fungus even at moderately high COD levels. One expedient was to remove fungal mass from the fermentation to keep the total biomass in the fermentation relatively low. The other was to increase the feed rate whenever the mycelium appeared slightly vacuolated and granular.

The results of a continuous fermentation of SO_2-soy whey using Gliocladium deliquescens and the technique of regularly removing part of the mycelial mass are shown in Figure 3. Mycelium was removed whenever the level climbed above 4 g/l. This removal was in addition to that achieved by continuous overflow from the fermenter. The feed rate was 5 ml/min of a feed containing 12,200 mg/l COD. Since the fermenter was of 18 l size, this represented a retention time of 60 hours. The SO_2 level was adjusted by mixing HCl soy whey with the SO_2-soy whey. The SO_2 level of the feed was increased in a stepwise fashion as indicated at 3 points in Figure 3. The temperature was in the range 25-28°C. The only chemical addition was sulfuric acid to adjust the pH.

The fermentation was begun by an inoculation dilution technique in which the fermenter was filled with soy whey diluted to five percent of its normal concentration; mycelium was added, and feeding with soy whey begun. The changes in COD expected if no microbial action occurred are shown by the line marked "theoretical".

The effluent from the fermenter was passed through a nylon mesh to remove mycelium and then through a second stage fermenter consisting of a 4-liter flask inoculated with a fungal and a bacterial isolates obtained from a soil enrichment culture. The medium of the soil enrichment culture was effluent from the Fungi Imperfecti fermentation. This second stage was aerated but not otherwise attended. COD levels from the second stage effluent are also shown in Figure 3.

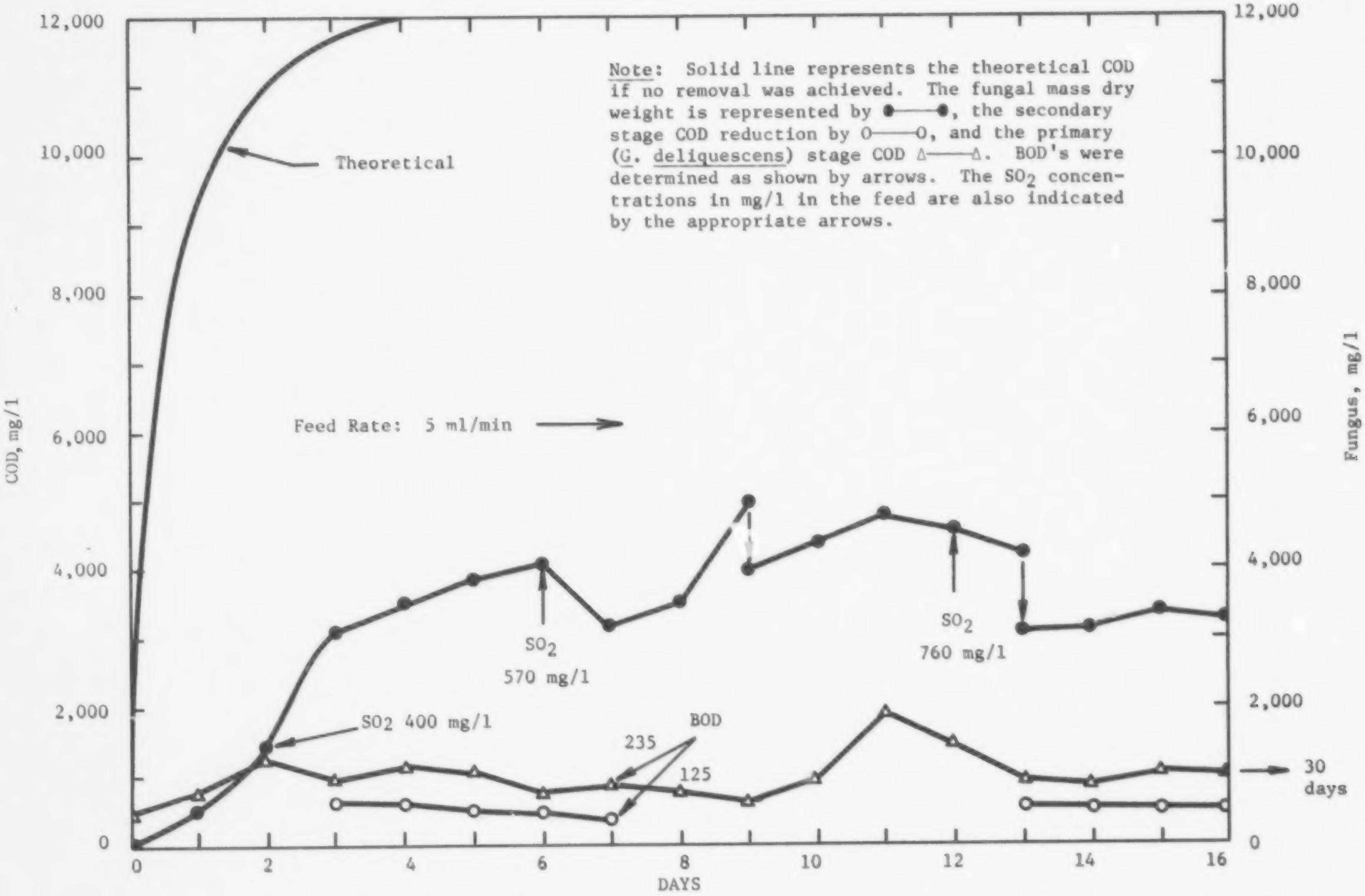


Figure 3. CONTINUOUS DIGESTION OF SO_2 SOY WHEY BY G. DELIQUESCENS. FUNGAL MASS CONTROL OF FERMENTATION.

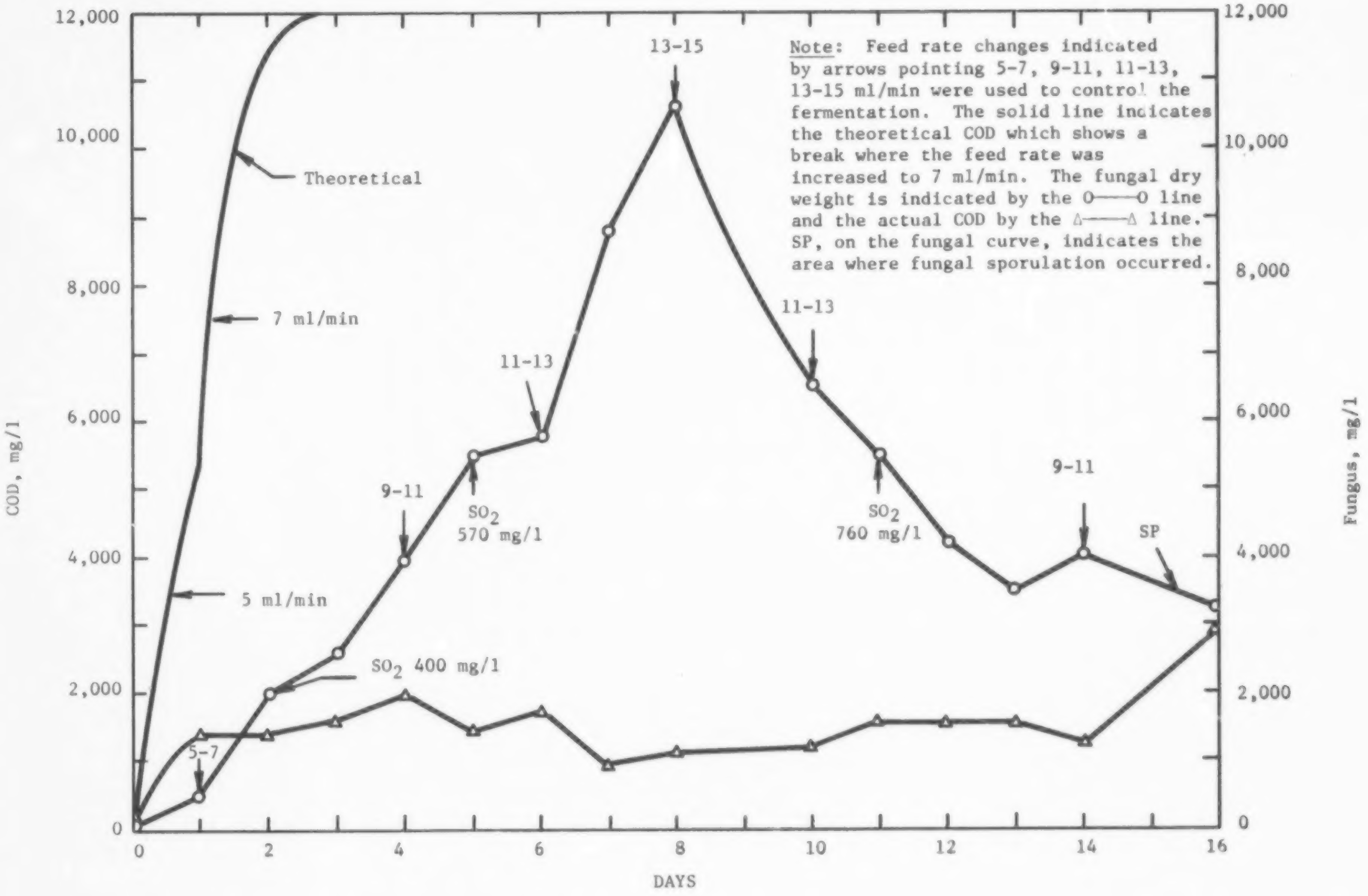
Note: Solid line represents the theoretical COD if no removal was achieved. The fungal mass dry weight is represented by ●——●, the secondary stage COD reduction by O——O, and the primary (G. deliquescens) stage COD Δ——Δ. BOD's were determined as shown by arrows. The SO_2 concentrations in mg/l in the feed are also indicated by the appropriate arrows.

The fermentation was successfully operated for 30 days before being discontinued. COD levels were reduced from 12,000 to about 1,100 in the first stage. BOD_5 levels were reduced to about 250. The second stage reduced COD and BOD_5 levels to about half these values. Total mycelium produced was about 5 grams per liter. An analysis of the performance on day 7 is shown in Table 3.

Table 3. Reduction of the Chemical Components of SO_2 Soy Whey by *G. deliquescens*

Test	Feed Soy Whey mg/l	After Fungal Digestion mg/l		% Reductions	
		Pri. Stage	Sec. Stage	Pri. Stage	Sec. Stage
COD	12,230	808	648	93.4	94.7
BOD_5	8,537	235	125	97.3	98.6
Carbohydrate	5,450	215		97.0	
Protein	3,950	420		89.4	
Phosphate (total)	144	43		70.0	
Nitrogen (Kjeldahl)	1,514	148		90.2	
SO_2	525	20		96.0	
Chlorides	848	550		35.0	
Fungus	-	3300		-	
Solids	11,650	2800		76.0	
Ash	2,397	1620		32.0	

Stabilization of the fermentation by controlling feed rates in accordance with appearance of the mycelium resulted in feed rates equivalent to 24 hours turnover time and COD levels in the effluent of about 1500. COD levels of the influent were 12,200. Results are shown in Figure 4. The buildup of mycelium to extremely high levels must be explained by a filtering action at the overflow point. Some difficulties were experienced with foaming. The rise in COD at the end of the experiment was due to starvation of the mycelium. In retrospect, it is apparent that feed levels were reduced when they should have been increased.



Note: Feed rate changes indicated by arrows pointing 5-7, 9-11, 11-13, 13-15 ml/min were used to control the fermentation. The solid line indicates the theoretical COD which shows a break where the feed rate was increased to 7 ml/min. The fungal dry weight is indicated by the O——O line and the actual COD by the Δ——Δ line. SP, on the fungal curve, indicates the area where fungal sporulation occurred.

Figure 4. CONTINUOUS DIGESTION OF SO_2 SOY WHEY BY G. DELIQUESCENS.

Aeration Requirements

Aeration requirements were calculated from the disappearance of dissolved oxygen after interrupting aeration of a stabilized fermentation. The assumption required in this method is that the COD reduction during the period of measurement be the same as the average COD reduction per unit of time before the aeration was interrupted. A mechanical stirrer was used to provide gentle agitation and homogenization of the digestor components during interruption of aeration. Curves for the consumption of dissolved oxygen are shown in Figure 5. In the case of corn waste, the feed rate was 20 ml/min of material containing 3650 mg/l COD. The effluent assayed 204 mg/l COD. Oxygen usage in an 18 l fermentation was seen to be 10.2 mg/min (0.57 mg/min/l x 18 l). COD reduction was 70 mg/min. This calculates to a usage of one pound of oxygen for every seven pounds of COD removed.

Data for calculation of oxygen usage for the soy fermentation were a feed rate of 4 ml/min into a fermenter of 15 l volume. The incoming feed contained 10,320 mg/l COD, and the effluent contained 2600 mg/l. The oxygen exhaustion curve shows disappearance of 0.33 mg O_2/min/l. These data indicate 5.5 pounds of COD removed per pound of dissolved O_2 used.

Properties of Mycelium

The mycelium yielded by the fermentations was threadlike in nature and readily filtered from the effluent by screens of up to 50 mesh size. It drained by gravity to about 12 percent solids and with vacuum filtration yielded a mass of 15 to 17 percent solids. The composition of *T. viride* mycelium grown on corn canning wastes is given in Table 4.

Table 4. Proximate Analysis of *T. viride* Mycelium on a Dry Weight Basis

	Percent
Nitrogen	9.5
Protein [a]	42
Fiber	9
Ash	9
Fat	4

[a] calculated from amino acid analysis

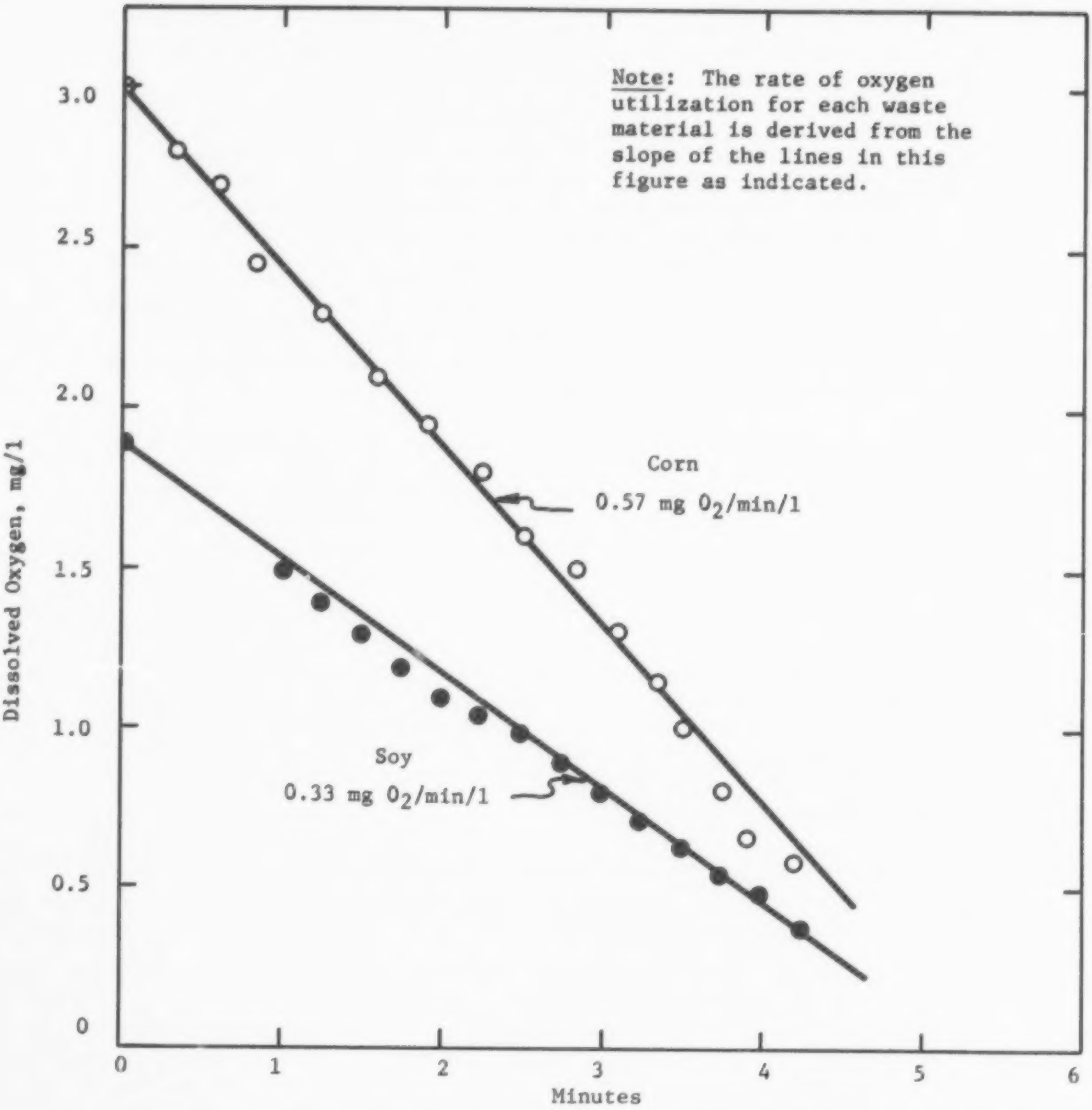


Figure 5. DISSOLVED OXYGEN UTILIZATION BY FUNGI GROWN ON CORN AND SOY WASTE IN CONTINUOUS CULTURE.

The amino acid composition together with those of casein and high lysine corn for reference are given in Table 5. It is to be noted that the analyses are in terms of amino acids per 16 grams of nitrogen. Since a substantial part of the nitrogen of the fungal mycelium is in materials other than protein, the total amino acids per 16 grams of nitrogen is considerably less than the expected 100 grams. In the case of T. viride I-23, the total is only 67 grams and in the case of G. deliquescens, 83 grams. This means that the amino acid values given in the table for T. viride can be multiplied by a factor of about 1.5 to give the grams of amino acid per 100 grams of protein. The amino acid distribution is quite favorable and compares well with high-lysine corn. Especially notable are a good lysine content, a high tryptophan content, a favorable leucine-to-isoleucine ratio, and a high threonine content.

Feeding Studies

The possible usefulness of the mycelium as a feed was probed in feeding experiments with weanling rats. The experiments were minimal in scope in that they used only three rats per group and were of three weeks duration. The principal objectives were to determine protein digestibility and utilization. Secondary objectives were to test palatability and look for any evidences of toxicity. Fungus was used as the sole protein source in the test diets except that selected amino acids were added to adjust the amino acid composition of the test diet to equal that of the casein control diet. Amino acids added were of L-methionine, L-serine, L-valine, L-leucine, L-tyrosine, and L-glutamic acid. Additions totaled less than 5 percent of the amino acids of the test diet. The total protein of test and control diets was 23 percent. The remainder of the diets was made up of starch, vegetable oil, minerals, and vitamins. Growth curves on individual rats are shown in Figure 6. It is seen that the average growth rate of control rats and test rats were identical. The digestibility of the fungal protein as determined by feed and fecal analyses was 90 percent. The net nitrogen utilization as determined by feed, feces, and urine analyses was 50 percent. That of the casein diet was 75 percent. It is important to note that about one-third of the nitrogen was nonprotein and so would not be expected to be utilized. It is also to be pointed out that the digestibility may be unrealistically high compared with that to be expected of a commercial product. The mycelium was broken in a Waring Blendor, then freeze-dried. On the other hand it has been observed that lysis can readily be produced by exposure to distilled water. It may be possible to release the protein before drying even in a commercial product.

Table 5. Amino Acid Analysis of Two Fungal Strains Compared to Several Standard Proteins (grams/16 grams nitrogen)

Amino Acid	*Trichoderma viride* on Corn Waste	*Gliocladium deliquescens* on Soy Whey	Casein	Soy Bean Meal	Opaque-2 Corn
Lysine	3.94	6.15	8.0	6.6	4.2
Histidine	1.67	2.33	3.0	2.5	3.5
Arginine	2.98	5.17	4.0	7.0	6.8
Aspartic Acid	6.49	8.41	7.0	8.3	10.0
Threonine	3.94	4.86	4.7	3.9	3.3
Serine	3.51	4.71	6.7	5.6	4.3
Glutamic Acid	8.98	9.47	25.0	18.5	18.7
Proline	4.34	4.25	11.0	5.0	8.6
Glycine	3.88	4.39	2.5	3.8	4.8
Alanine	4.76	5.99	3.0	4.5	6.5
Cystine	1.38	1.42	1.0	1.2	1.7
Methionine	1.20	1.19	3.5	1.1	1.4
Valine	4.48	4.85	7.7	5.2	4.9
Isoleucine	3.52	4.06	6.5	5.8	3.2
Leucine	5.35	6.18	9.7	7.6	8.4
Tyrosine	2.44	3.29	6.5	3.2	3.9
Phenylalanine	2.76	3.96	5.9	4.8	4.4
Tryptophan	1.80	2.31	1.2	1.2	1.3

The protein content of these fungal mycelia is between 42 and 45 percent, based on the amino acid analyses.

Black and Bolling, Amino Acid Handbook, 1960, was used for the amino acid reference values.

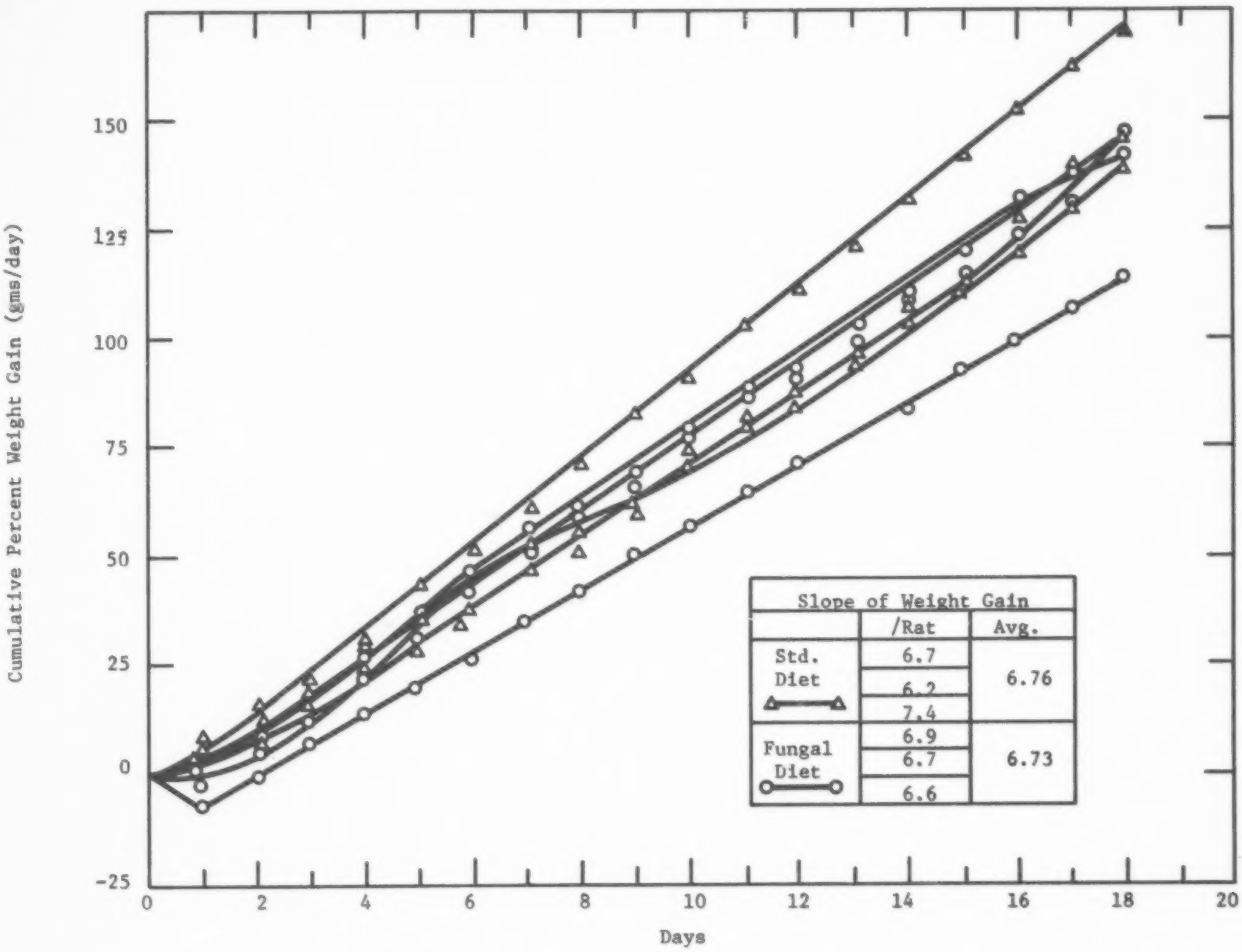


Figure 6. RAT GROWTH CURVES

Aeration cost estimates are based on the laboratory finding that 0.14 lb of dissolved oxygen was used per lb of COD destroyed. The assumption was made that 1 hp hr will provide 2 lb of dissolved oxygen. The $500 investment per horsepower is meant to cover the cost of the aeration equipment, the lagoon, and costs of control equipment. This estimate seems reasonably conservative. The investment has been amortized over 10 years at 8 percent interest. It was assumed that the COD load is 2500 mg/l and the equipment is in use 50 days per year.

Labor costs were calculated assuming eight hours of labor a day at $100 cost per day (including overhead) to operate a 2,500,000 gal/day installation.

Filtering and drying costs represent a gross estimate and are meant to cover labor, capital equipment, power, and other costs associated with this operation.

Sales returns assume the product would bring the same price as soy oil meal with which it compares in protein content and quality.

Estimates for soy waste processing have similarly been attempted (Table 7). Nitrogen and phosphate supplies are probably adequate in the incoming feed and so do not need to be added. Aeration requirements are similar to those of corn per pound of COD removed, but the costs are lower because the amortization is spread over constant operation instead of over fifty days operation per year. The constant operation does raise the need for heat in the winter in northern climates. No attempt has been made to estimate heating costs because it is not known whether waste heat would be available from processing operations.

Table 7. Economy of Soy Waste Treatment

Item	Amount		Cents/lb product
H_2SO_4	0.1 lb		$ 0.14
Aeration	0.28 lb O_2/lb product (1 hp hr = 2 lb DO) (Power cost = 1.5¢/kw hr)		0.16
	Investment at $500/hp		0.12
Labor	$200 a day		0.17
Heat			--
		Subtotal	0.54
Filtering and Drying			2.00
		Total	2.66
Selling Price			$ 3.75

Rat feeding experiments with _G. deliquescens_ mycelium from soy why were less salutary. The rats refused to eat mycelium grown on SO_2-soy whey. They did consume mycelium from HCl soy whey, but in only moderate amounts. Growth rates were lower than with the casein control diets, but only enough mycelium was available for a 7-day test. The results must therefore be considered inconclusive.

ECONOMIC ESTIMATES

Only crude estimates of the cost of waste treatment by fungi can be made from laboratory data alone. Larger-scale trials will be required as a basis for more accurate estimation. Estimates for costs of application of fungi to corn processing wastes are summarized in Table 6. The estimates were based on recovery of 0.5 pound of dried mycelium for each pound of COD utilized. This is a conservative estimate based on accumulated experience.

The amount of ammonium sulfate added is sufficient to yield a product with 60 percent protein if all the nitrogen is converted to protein. The amount of sodium dihydrogen phosphate was selected to give the phosphate-to-nitrogen ratio that has given the best control of fermentation. The amount of sulfuric acid is based on experience with the Green Giant corn waste stream. The amount actually required will depend, in some degree, on the amount and kind of materials in the water used in the plant.

Table 6. Economy of Corn Waste Treatment

Item	Amount		Cents/lb fungal product
N $(NH_4)_2SO_4$	0.45 lb		$ 0.67
PO_4 = NaH_2PO_4	0.022 lb		0.20
H_2SO_4	0.10 lb		0.14
Aeration	0.28 lb dissolved oxygen (1 hp hr = 2 lb DO) (Power cost = 1.5¢/kw hr)		0.16
	Investment at $500/hp		0.70
Labor	$100 per day		0.38
		Subtotal	1.97
Filtering and Drying			2.00
		Total	4.25
Selling Price			$ 3.75

A plant handling 3,500,000 gallons of waste per day with a COD load of 8,000 mg/l has been assumed.

It has been assumed that one pound of dry product is obtained per two pounds of COD removed.

CONCLUSIONS

The use of Fungi Imperfecti to remove BOD_5 from food processing waste streams with production of a mycelium with value as a by-product appears promising from these studies. In the case of the corn stream, the several objectives of achieving a low BOD_5 in the effluent, attaining a short digestion cycle, attaining a stable fermentation, producing a mycelium that is easily recovered, and producing a mycelium that has potential feed value seem to have been satisfactorily fulfilled. In the case of the soy stream, the BOD removal was less satisfactory (although still above 97 percent), and the promise of the mycelium as a feed remains to be confirmed.

The economics of the process appear attractive. In the case of corn canning wastes, it appears that sale of the dried mycelium as a feed should cover about 85 percent of the treatment costs. In the case of soy wastes, a profit should be realized. The more favorable economics in the case of soy wastes is due to year-round operation and the adequacy of nitrogen and phosphate in the waste stream. In either case, the economics depend very much on drying costs, and these are gross estimates. Arrangements such that the mycelium could be fed without drying would allow very favorable economics. A lesser factor in economics is the low aeration requirements. Our estimates of these requirements are based on laboratory measurements only and so cannot be considered proved. The measures of aeration needs were more favorable than expected.

It must of course be realized that actual use of the mycelium in feed will require more extensive tests to prove its safety. Use as a human food of high protein content and good protein quality is an ultimate possibility.

SUMMARY

Forty-eight species of eighteen genera of the Fungi Imperfecti were screened for those fungal candidates best able to rapidly convert soluble and suspended organic material (as measured by BOD) from corn and soy food-processing waste streams to mycelial protein. Rapidly growing fungal strains were selected which were readily removed from the digested waste effluents by coarse filtration. _Trichoderma viride_, _Gliocladium deliquescens_, and either _Aspergillus oryzae_ or

G. deliquescens gave the best results on corn, soy and SO_2-containing soy wheys, respectively. Optimal growth conditions included pH of 3.2 to 3.5, and a temperature of 30°C. Oxygen requirements were relatively low (1 lb O_2/6 to 7 lb COD removed). Nitrogen and phosphate additions were required for the corn digestion system, and additions of sulfuric acid were necessary to adjust the pH. These studies were done in 125 ml flasks containing nonsterile corn and soy wastes. The growth conditions that resulted in the highest fungal yield and greatest reduction in BOD and total solids were incorporated into 20-liter continuous culture digestions. Corn waste was reduced from an initial BOD level of 1600 mg/l to 25 mg/l in 24 hours. Soy wastes were reduced from 6200 mg of BOD/l to 125 mg of BOD/l in 36 hours in incubation. Studies of rapid fungal digestion of soy whey containing 700 mg/l of SO_2 resulted in selction of A. oryzae and G. deliquescens strains which removed SO_2 from the medium. Mycelial yields were approximately 50 to 60 g of dry mycelium per 100 g of COD utilized. The stability of the continuous fermentation with corn waste was demonstrated in a fermentation run of 140 days' length. Runs of 30 days' length have been conducted with soy whey. The protein content of mycelium recovered from the continuous culture corn digestion system was 42 percent. The recovered mycelium was light tan in color and bland in taste and smell. Feeding trials in weanling rats using T. viride grown in corn waste as the protein source gave a growth response equal to that seen with a standard casein rat diet. Digestibility was 90 percent, and no toxicity was observed in a three-week trial. Feeding trials were inconclusive with rats fed G. deliquescens fungal protein from the soy whey fermentation due to a palatability problem. Economic estimates based on the experimental results showed the fungal product to be comparable in cost to soil oil meal.

Results on both soy and corn wastes gave definite encouragement that the commercial use of selected strains of certain species of Fungi Imperfecti to remove BOD in a readily harvested form is practical.

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COMBINED TREATMENT OF DOMESTIC, AND INDUSTRIAL WASTES BY ACTIVATED SLUDGE

by

John L. Graham and John W. Filbert*

INTRODUCTION

Purpose of Project

Many small cities provide wastewater treatment services to local industry. In the Pacific Northwest, food processing plants located within cities often seasonally discharge a greater pollutional load to the municipal sewerage system than all domestic and commercial discharges combined. The construction and operation of conventional wastewater treatment plants to treat the combined domestic and industrial flows can be a financial burden to the citizens and the industry. In addition, most conventional approaches to treatment plant design have been found to be inadequate to provide the necessary degree of treatment, the operational flexibility, and the system stability required.

A new approach is needed in the design of small treatment plants which results in minimum costs, maximum effluent quality, and maximum flexibility to meet the peak industrial waste loads frequently encountered. One possibility which may fit these criteria is the completely aerobic treatment system. A system of this type has been constructed by the City of Dallas, Oregon, with the aid of a municipal research and development grant provided by the Federal Water Quality Administration.

The treatment system constructed at Dallas has not previously been proven in full-scale operation. There are, for this reason, several areas in which more information is required to refine design and operational criteria. The main purpose of this demonstration project is to provide this information.

Project Objectives

The major objectives of this project are as follows:

To demonstrate the economics and efficiency of the completely aerobic treatment method when applied to the treatment of combined domestic and

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industrial wastes, primarily food processing in origin.

To demonstrate the application of aerobic digestion, mechanical surface aeration and earthen embankment construction.

To demonstrate the flexibility of the system in handling rapidly changing industrial waste loadings due to the seasonal nature of canning operation.

GENERAL TREATMENT DESCRIPTION

Waste flow from the City's collection system enters the plant through a 36-inch diameter influent sewer at the pump station (1). (See Figure 1 for locations). The raw waste is pumped through an 18-inch pipeline to the headworks (2). The waste is shredded by the comminutor (3) and then flows to the aeration basin splitter box (4) where it is discharged to one or both of the 124-foot square aeration basins (5).

The overflow from the aeration basin flows by gravity to the 60-foot diameter final clarifier (6) where the activated sludge is settled.

The activated sludge to be returned to the aeration basin is removed from the clarifier by means of six suction pipes mounted on the revolving clarifier mechanism and flows by gravity to the return sludge pump station located nearby (7). Two sludge pumps, sized to return 25 to 100 percent of the plant dry weather design flow, lift the activated sludge back up to the splitter box (4).

Excess, or waste sludge is collected on the bottom of the clarifier by a revolving scraper arm and pumped directly to the 90-foot diameter aerobic digester (8) through one or both sludge pumps located in the control building (9).

The effluent from the clarifier flows by gravity through flow measurement box (10) to the chlorine contact channel (11), and is finally discharged through the outfall (12) into LaCreole Creek.

The digested sludge is pumped through a sludge pump located in the control building to the two, 67,000 square foot, humus storage ponds (13) where it is further stabilized and dried. The supernatant from the humus ponds flows by gravity to the plant influent line (1).

A schematic diagram of the system is shown on Figure 2. Figures 3, 4 and 5 show the final effluent from the chlorine contact channel, the aeration basins and the clarifier.

The system treats a combination of cannery wastes, domestic wastes, a limited quantity of slaughterhouse wastes and an occasional flow of glue spreader wastes from a plywood plant. The plant was designed to meet the Oregon State Department of Environmental Quality requirements, which state that the effluent to the receiving stream may contain not more than 20 mg/l each of BOD and suspended solids.

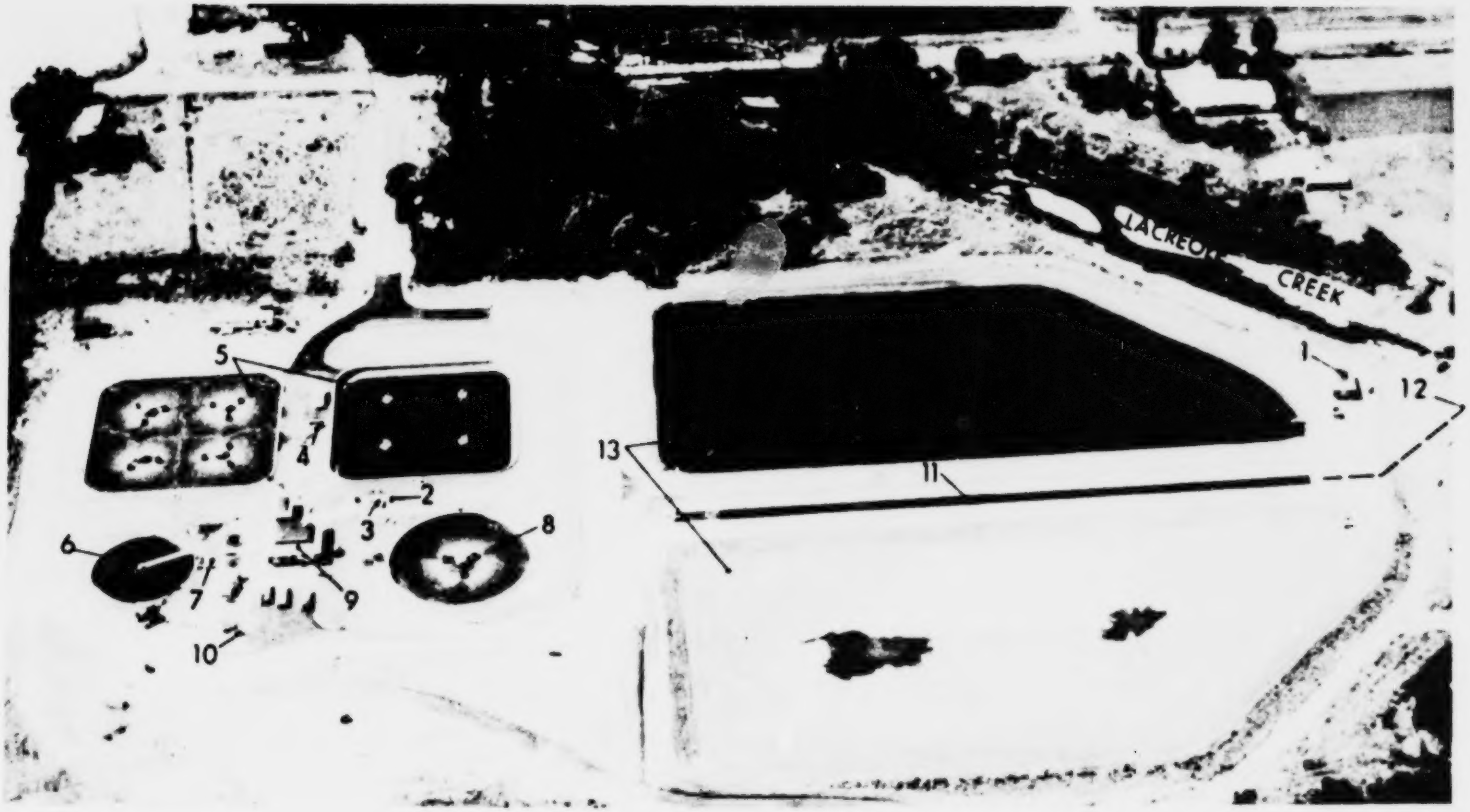

FIGURE 1 **DALLAS WATER POLLUTION CONTROL PLANT**

1. RAW SEWAGE PUMP STATION
2. HEADWORKS
3. COMMINUTOR
4. AERATION BASIN SPLITTER BOX
5. AERATION BASINS (2)
6. FINAL CLARIFIER
7. RETURN SLUDGE PUMP STATION
8. AEROBIC DIGESTER
9. CONTROL BUILDING
10. FLOW MEASUREMENT BOX
11. CHLORINE CONTACT CHANNEL
12. OUTFALL SEWER
13. SLUDGE LAGOONS (2)

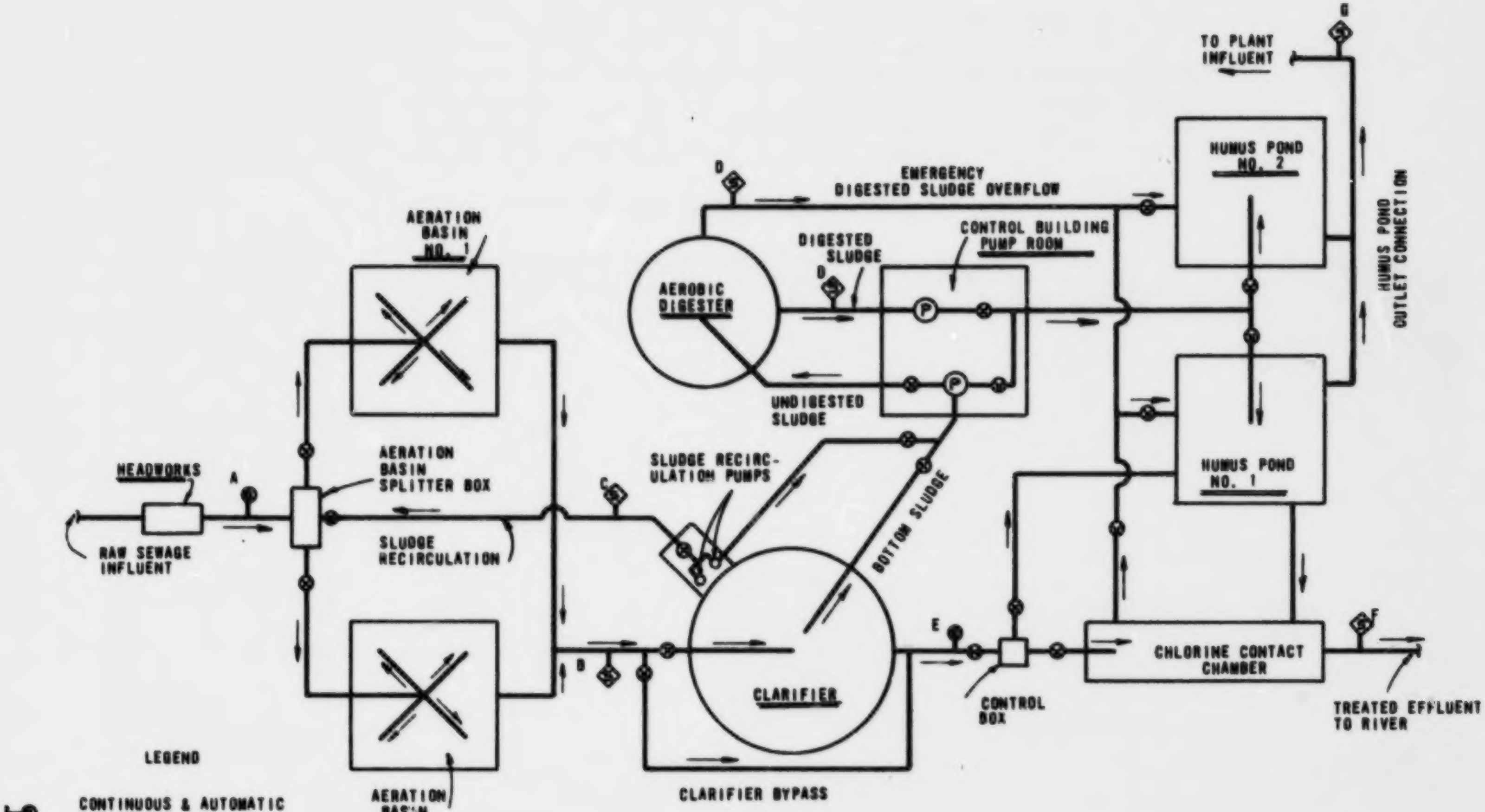
HEADWORKS
RAW SEWAGE INFLUENT
A
AERATION BASIN SPLITTER BOX
AERATION BASIN NO. 1
AERATION BASIN NO. 2
SLUDGE RECIRCULATION
C
B
SLUDGE RECIRCULATION PUMPS
CLARIFIER
CLARIFIER BYPASS
BOTTOM SLUDGE
D
AEROBIC DIGESTER
DIGESTED SLUDGE
UNDIGESTED SLUDGE
CONTROL BUILDING PUMP ROOM
P
EMERGENCY DIGESTED SLUDGE OVERFLOW
E
CONTROL BOX
CHLORINE CONTACT CHAMBER
F
TREATED EFFLUENT TO RIVER
HUMUS POND NO. 1
HUMUS POND NO. 2
HUMUS POND OUTLET CONNECTION
G
TO PLANT INFLUENT
LEGEND
CONTINUOUS & AUTOMATIC SAMPLING POINT
OTHER SAMPLING POINTS
CONTINUOUS FLOW METERING
CONTROL VALVE OR GATE
CONSTANT SPEED PUMP

FIGURE 2

CITY OF DALLAS, OREGON
TREATMENT SYSTEM

SCHEMATIC PLAN

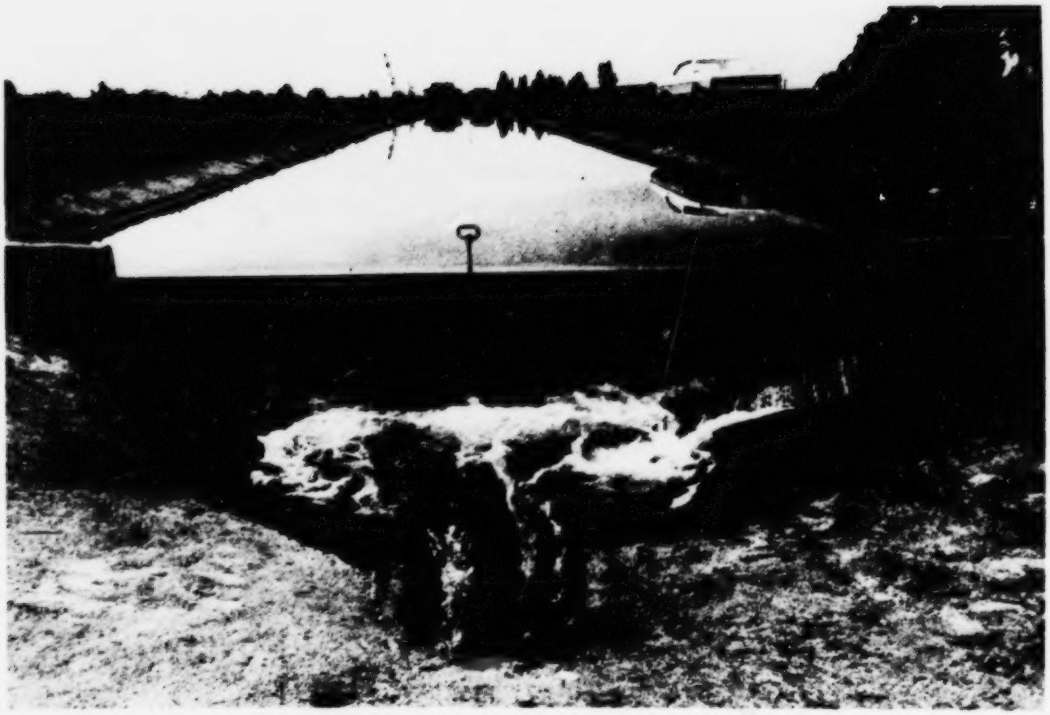

Figure 3. CHLORINE CONTACT CHANNEL AND FINAL EFFLUENT

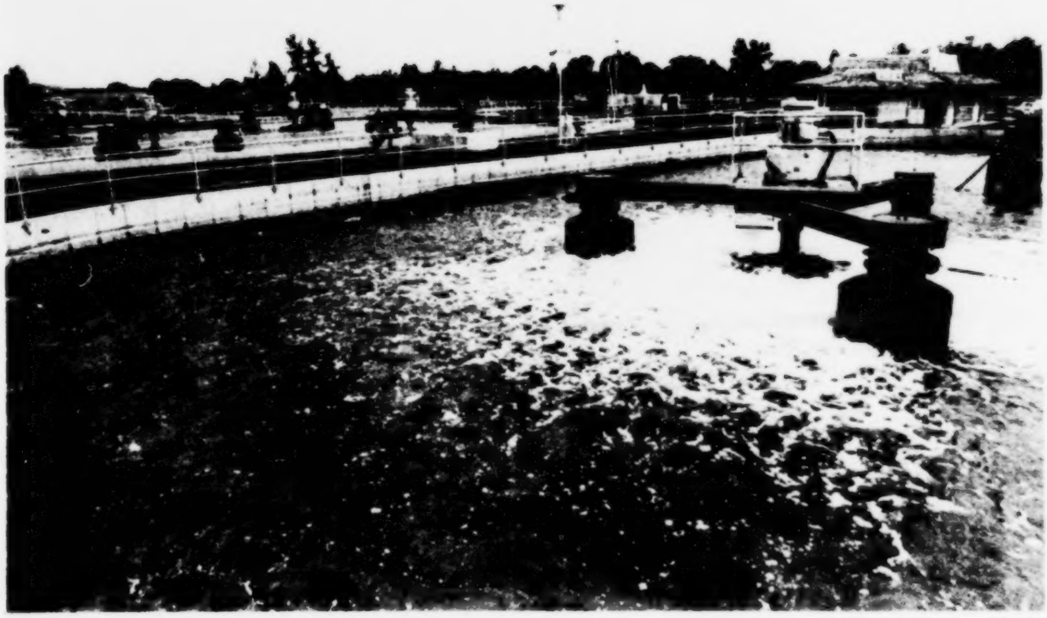

Figure 4. AERATION BASINS

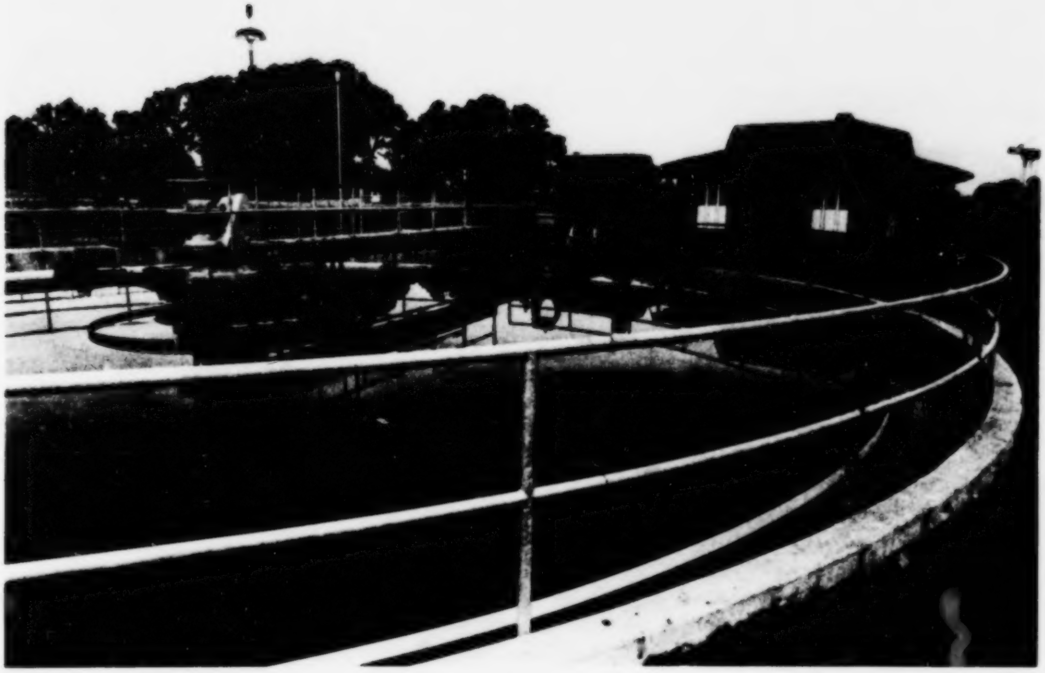

Figure 5. FINAL CLARIFIER

DESIGN CONCEPT AND CRITERIA

The design was based on the need to minimize the following shortcomings often associated with conventional activated sludge designs: high construction costs; high operating labor costs; need for highly trained operators; susceptibility to upset by shock organic, hydraulic and toxic loads; and waste solids handling, stabilization and disposal problems.

System design was undertaken to eliminate or reduce the foregoing shortcomings. The primary clarifier and grit removal facility were eliminated. The aeration capacity was increased to compensate for the greater organic load to the aeration basins. Grit will be settled out in these basins to be removed periodically by heavy equipment.

Aerobic digestion was employed in place of the higher cost conventional anaerobic digestion.

Earthen basins, with shotcrete sideslope linings were used in place of higher cost reinforced concrete construction.

Automation of many plant operations which would normally require operator attention helps to reduce operating costs.

Employing the complete-mix activated sludge principle, maintaining a conservative range of organic loadings, and adequate hydraulic surge capacity within the aeration basins serve to minimize susceptibility to process upset by shock organic, hydraulic and toxic loads.

Waste solids handling and disposal problems have been minimized by the use of aerobic digestion and automatically controlled sludge pumping to the digester and from the digester to the humus storage ponds.

The design concepts used more nearly parallel those for industrial waste treatment systems as opposed to strictly domestic waste treatment; e.g., omission of primary clarifiers, use of mechanical surface aerators and earthen basin construction.

Table 1 lists the treatment plant design criteria.

STUDIES AND OPERATION

Operation

The operation of the plant has been varied to facilitate determination of treatment efficiency and flexibility. Among these variations are the following: operation at MLSS levels ranging from 700 mg/l to 3,000 mg/l; aeration times between 3.6 hours and

60 hours (due to variations in flow); and digester detention times from 5 days to 30 days.

Sampling and Testing

Influent and effluent samples are composited automatically in proportion to plant flow. Additional samples (see Figure 2) are composited manually during the 8-hour operating shift. All samples are refrigerated prior to analysis. A specified minimum number of tests per week are run on an established schedule.

Table 1. Treatment Plant Design Criteria

Population	
Present	5,500
Design	10,400
Biochemical Oxygen Demand (BOD_5)	
Canning season	7,080 lb/day
Non-canning season	2,080 lb/day
Population equivalent (@ 0.17 lb BOD/ person/day)	
Canning season	41,600
Non-canning season	12,200
Flow	
Average	2.0 mgd
Maximum	6.0 mgd
Aeration Basins	
Aeration time at design flow	24 hours
Clarifier	
Surface overflow rate	700 gal/day/ft^2

PRELIMINARY RESULTS AND DISCUSSION

The demonstration program is about 50 percent complete and the plant has been in operation for about six months. The preliminary data shows the effluent quality well within the requirements set by the State Department of Environmental Quality. The average effluent BOD for the six-month period was 7 mg/l and the average effluent suspended solids 12 mg/l. These results were obtained with organic loading rates ranging from 0.03 to 0.42 lb BOD_5/ lb MLVSS.

The relationship between organic loading and effluent BOD_5 is shown on Figure 6. The data was plotted on this figure by computer and the curve generated by the method of least squares fit. The effluent BOD_5 was affected very little by changes in the organic loading. This provides an indication of the flexibility and efficiency of the system under various loading conditions.

A further indication of plant flexibility is shown by Figure 7. The effluent BOD_5 was little affected by wide variations of influent BOD_5. The influent waste strength has varied from nearly 300 mg/l BOD_5 to 30 mg/l BOD_5.

The chronological correlation between flow rate and effluent suspended solids (SS) is shown on Figure 8. Suspended solids concentration in the effluent was generally not affected by changes in the flow rate. The high effluent SS near the end of November occurred during a period of relatively low flow. However, this peak coincided with a shock loading of phenolic glue waste containing a high concentration of poorly settling solids which were readily carried over the clarifier weir. The effluent SS peak near the middle of December coincided with a very high flow rate. The shock load of glue waste adversely affected the settleability of the activated sludge. The system was not fully recovered when the high flow occurred and a portion of the activated sludge was carried over the weir. However, by the last week in December, the system had completely recovered even though the flow remained high.

The relationship between pH and alkalinity in the aeration basin is shown on Figure 9. The correlation appears to be reasonably consistent. That is, a pH drop corresponds to a reduction in alkalinity. The periods of peak alkalinity coincide rather closely with high flows. This is because, during high flow, a higher total amount of alkalinity enters the aeration basin even though the concentration is less. However, the same amount is removed through nitrification in the basin as during low flow periods, so a higher concentration is measured in the basin.

The data shows that a significant amount of nitrification has occurred in the system, however, it appears that the alkalinity in the influent flow is enough to sufficiently buffer the system, since the minimum pH recorded was 6.5. A statistical analysis of the data (Figure 10) shows that 90 percent of the time the aeration basin alkalinity was 25 mg/l or greater.

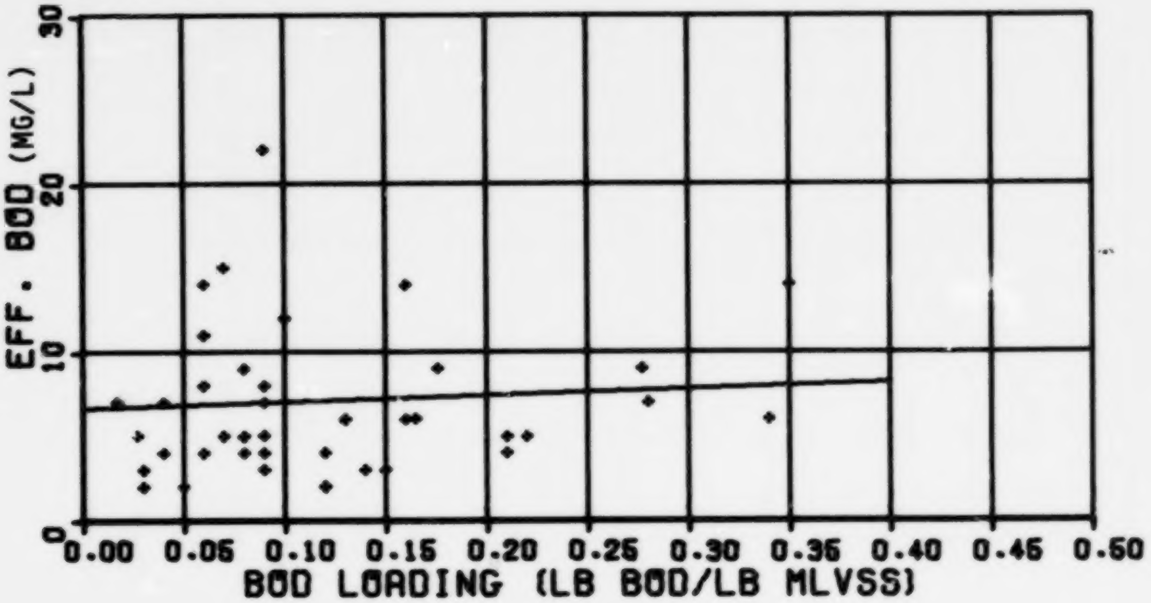

FIGURE 6

CORRELATION BETWEEN EFFLUENT BOD AND BOD LOADING

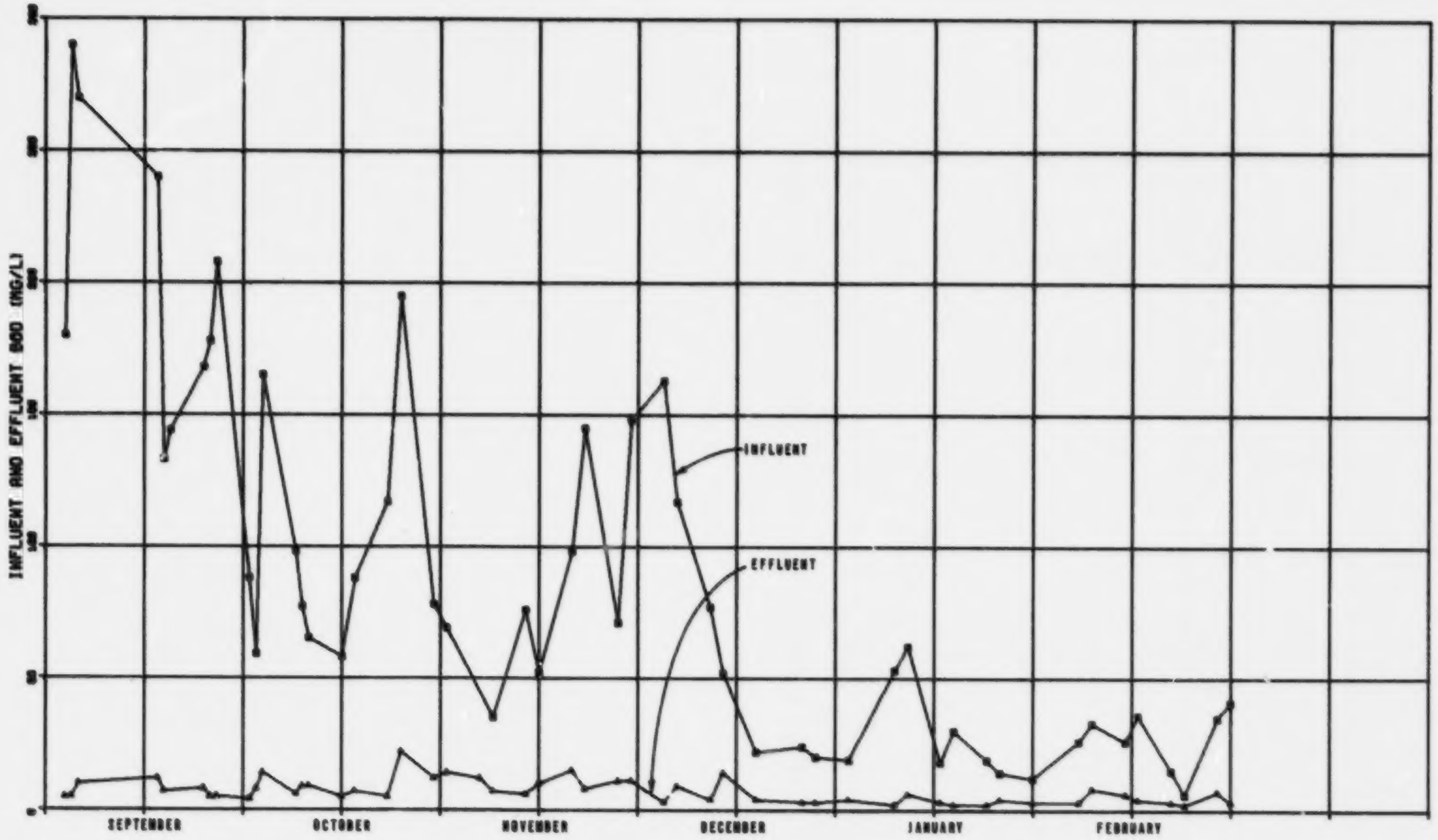

FIGURE 7
CHRONOLOGICAL COMPARISON OF INFLUENT AND EFFLUENT BOD

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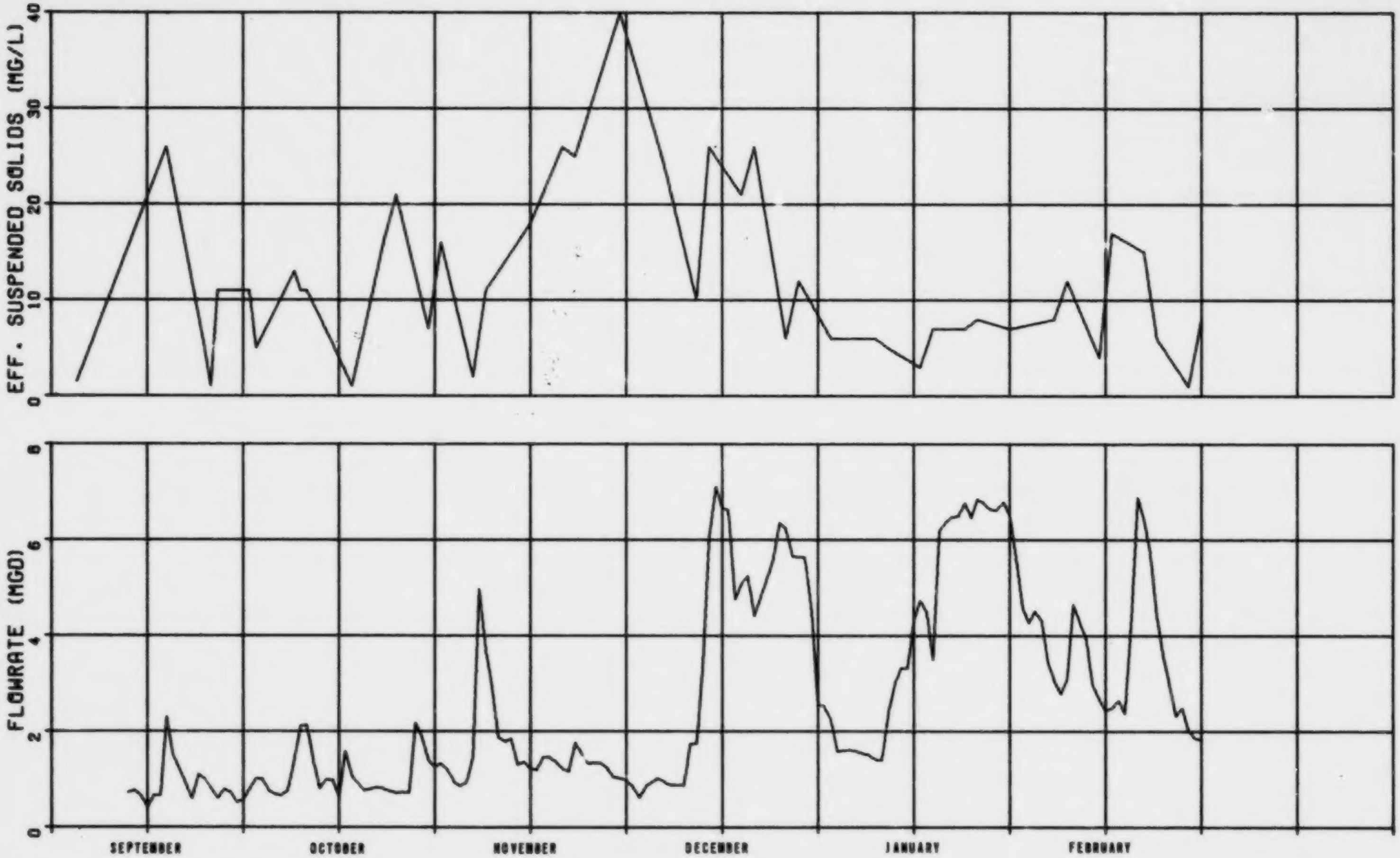

FIGURE 8

CHRONOLOGICAL PLOT OF FLOWRATE AND EFFLUENT SUSPENDED SOLIDS DATA

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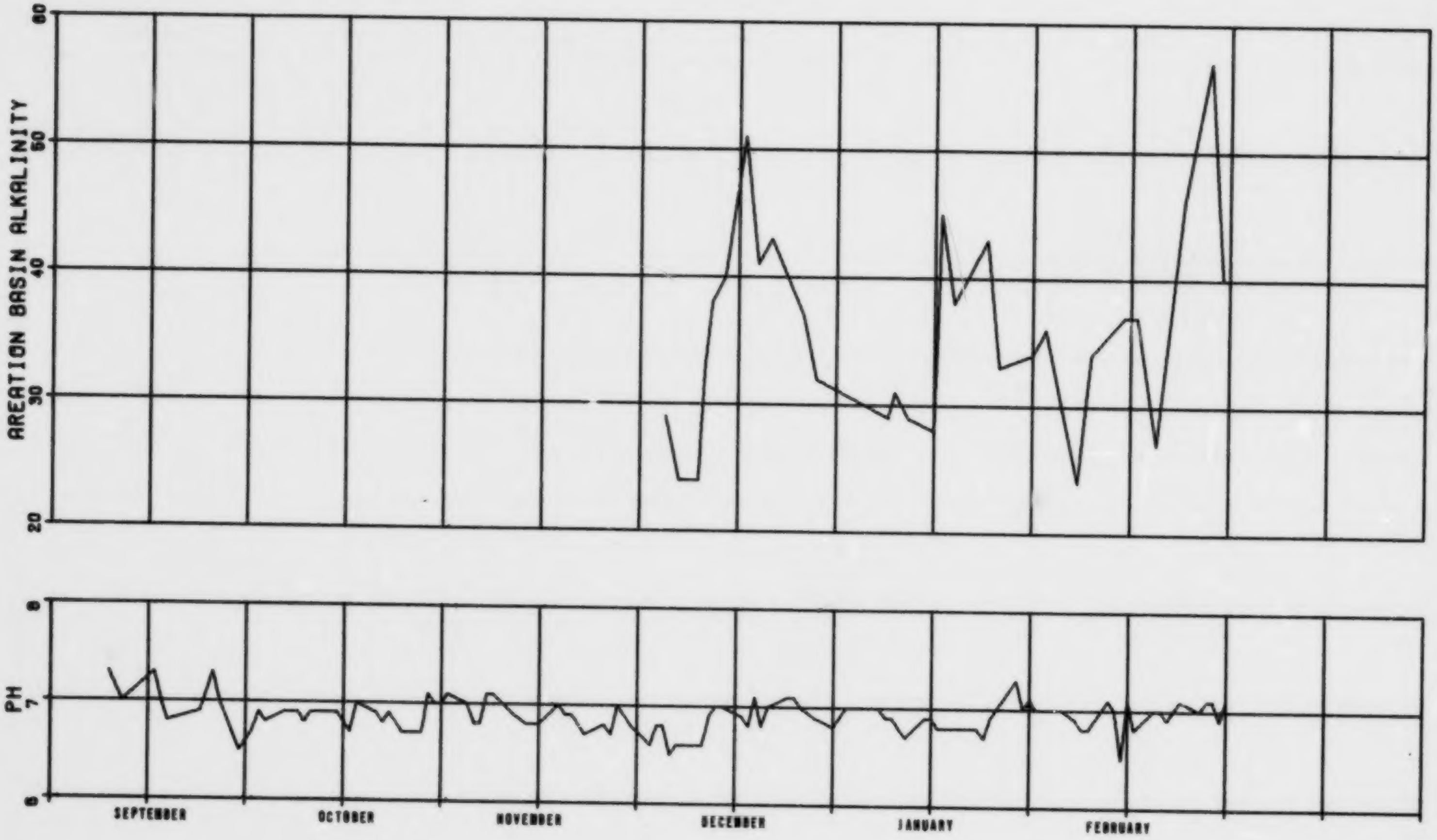

FIGURE 9

AERATION BASIN pH AND ALKALINITY

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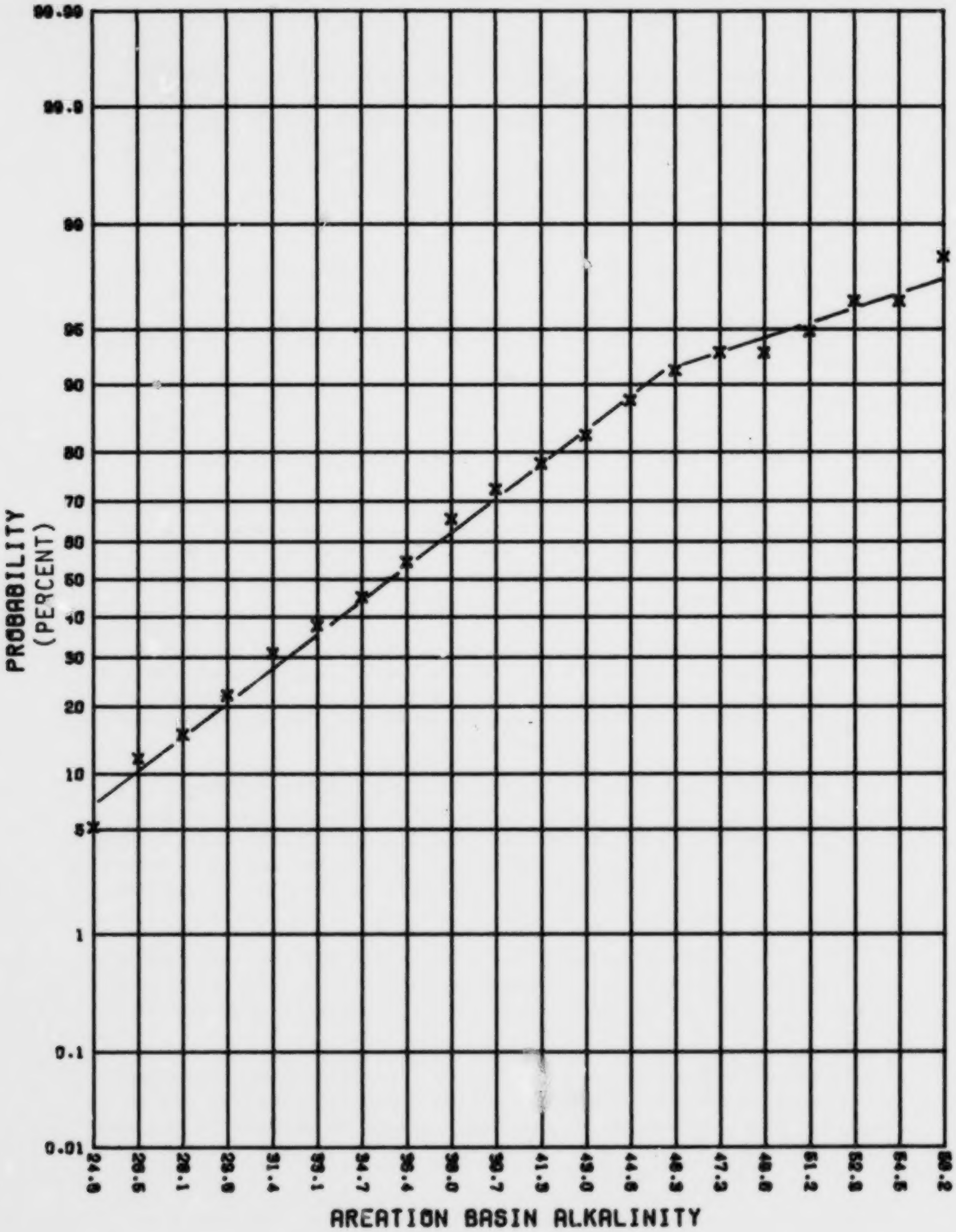

FIGURE 10

STATISTICAL ANALYSIS OF AERATION BASIN ALKALINITY DATA

Figures 11 and 12 show data for Total Kjeldahl Nitrogen (TKN), Ammonia Nitrogen (NH_3-N), and Nitrate Nitrogen (NO_3-N) in both influent and effluent flows. Figure 11 shows a significant reduction in both TKN and NH_3-N through the plant, and Figure 12 shows an increase in NO_3-N. The decrease in NH_3-N with a corresponding increase in NO_3-N shows the occurrence of nitrification in the system.

Figure 13 shows data for total and orthophosphate (T-PO_4 and O-PO_4). The T-PO_4 curves are difficult to analyze due to missing data. However, it appears that a slight reduction in T-PO_4 has occurred. The average removal over the period was about 10 percent and the average effluent T-PO_4 was 3.8 mg/l.

The O-PO_4 curves show a consistent conversion of T-PO_4 to O-PO_4 as may be expected. The effluent O-PO_4 averaged 3.2 mg/l. However, there was a net reduction in total phosphorous content.

The plant was operated at various MLSS levels, as mentioned previously, to determine its flexibility. Figure 14 shows the probability of occurrence of the various MLSS levels. Seventy percent of the time the MLSS level was between 1,000 mg/l and 2,200 mg/l. The median MLSS value for this period was 1,400 mg/l.

Sludge Volume Index (SVI) was used as an indication of the settleability of the activated sludge. A statistical analysis of the data (Figure 15) shows that the SVI was 90, or less, 92 percent of the time. However, no apparent increase in effluent suspended solids was observed with SVI values up to 130.

Figure 16 shows that about 50 percent of the time the flow was 2.0 million gallons per day (mgd), or greater. This is significant because the average plant design flow was 2.0 mgd. These high flows were due to the large quantity of rainfall received during December and January, and a high degree of infiltration into the collection system.

The high flows were also partially responsible for the low strength of the influent wastewater as shown on Figure 17. This curve indicates that about 70 percent of the time the influent BOD_5 was 110 mg/l, or less.

The plant efficiency is confirmed by the statistical data plotted on Figures 18 and 19. The total effluent BOD_5 (Figure 18) was 16 mg/l, or less, 96 percent of the time. About 95 percent of the time the dissolved BOD_5 in the effluent was 7 mg/l, or less (Figure 19).

Waste sludge accumulated at the rate of about 1,800 pounds per day. This figure is based on calculations using average data obtained and McKinney's activated sludge equations. The average BOD removal per day was about 1,800 pounds resulting in approximately one pound

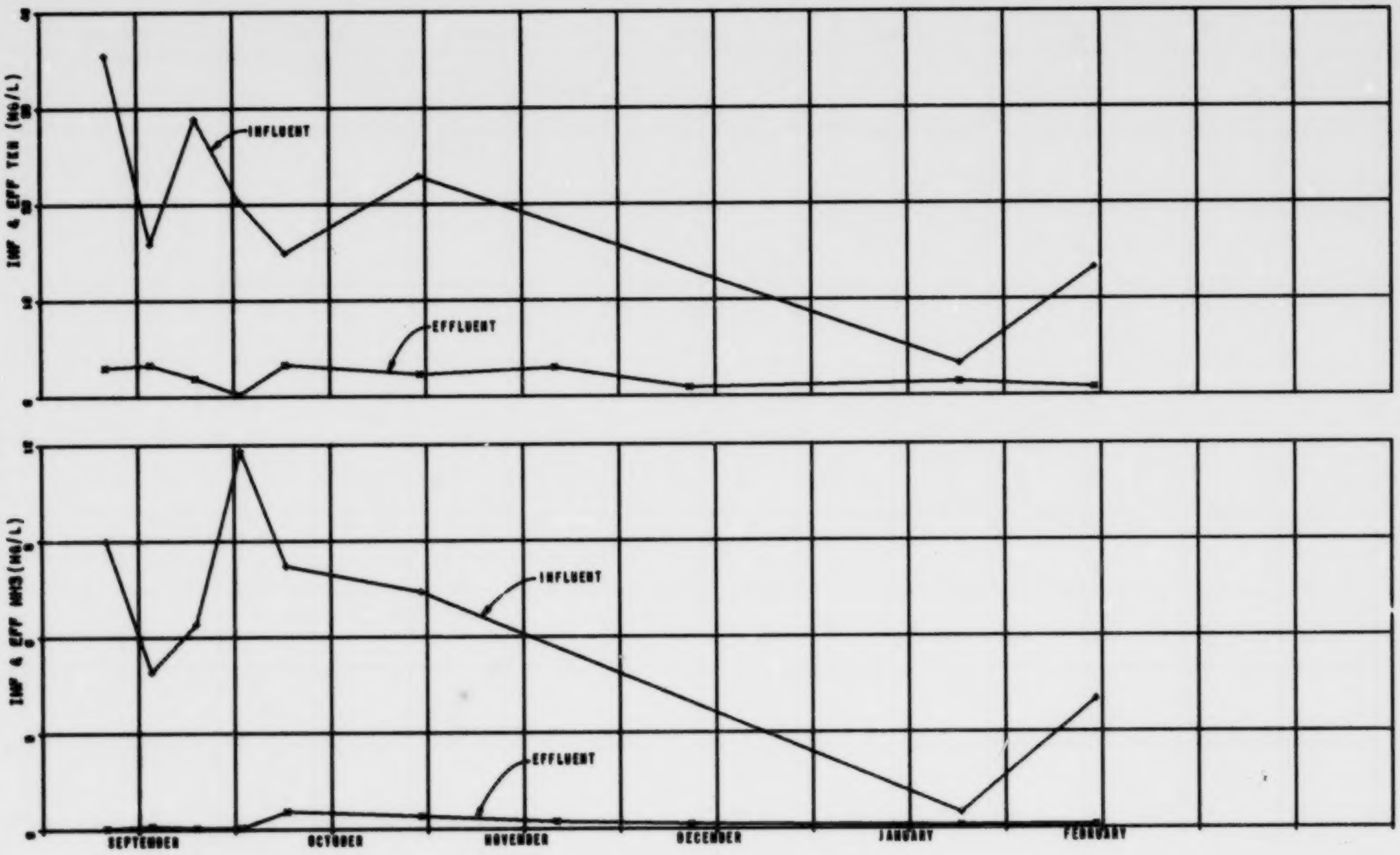

FIGURE 11

TOTAL KJELDAHL NITROGEN AND AMMONIA NITROGEN DATA FOR INFLUENT AND EFFLUENT FLOWS

G9002.7

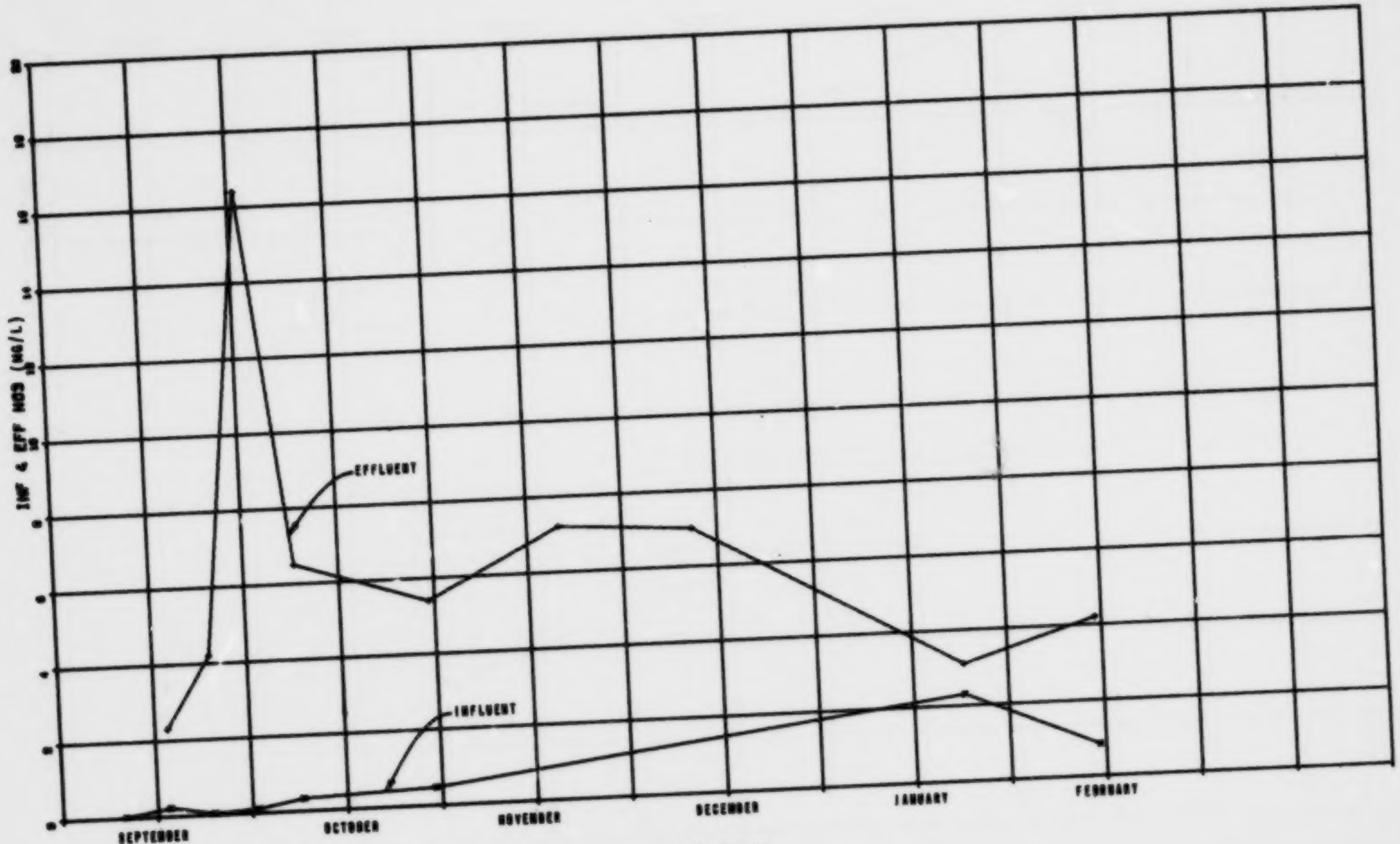

FIGURE 12

INFLUENT AND EFFLUENT NITRATE NITROGEN DATA

CS002.7

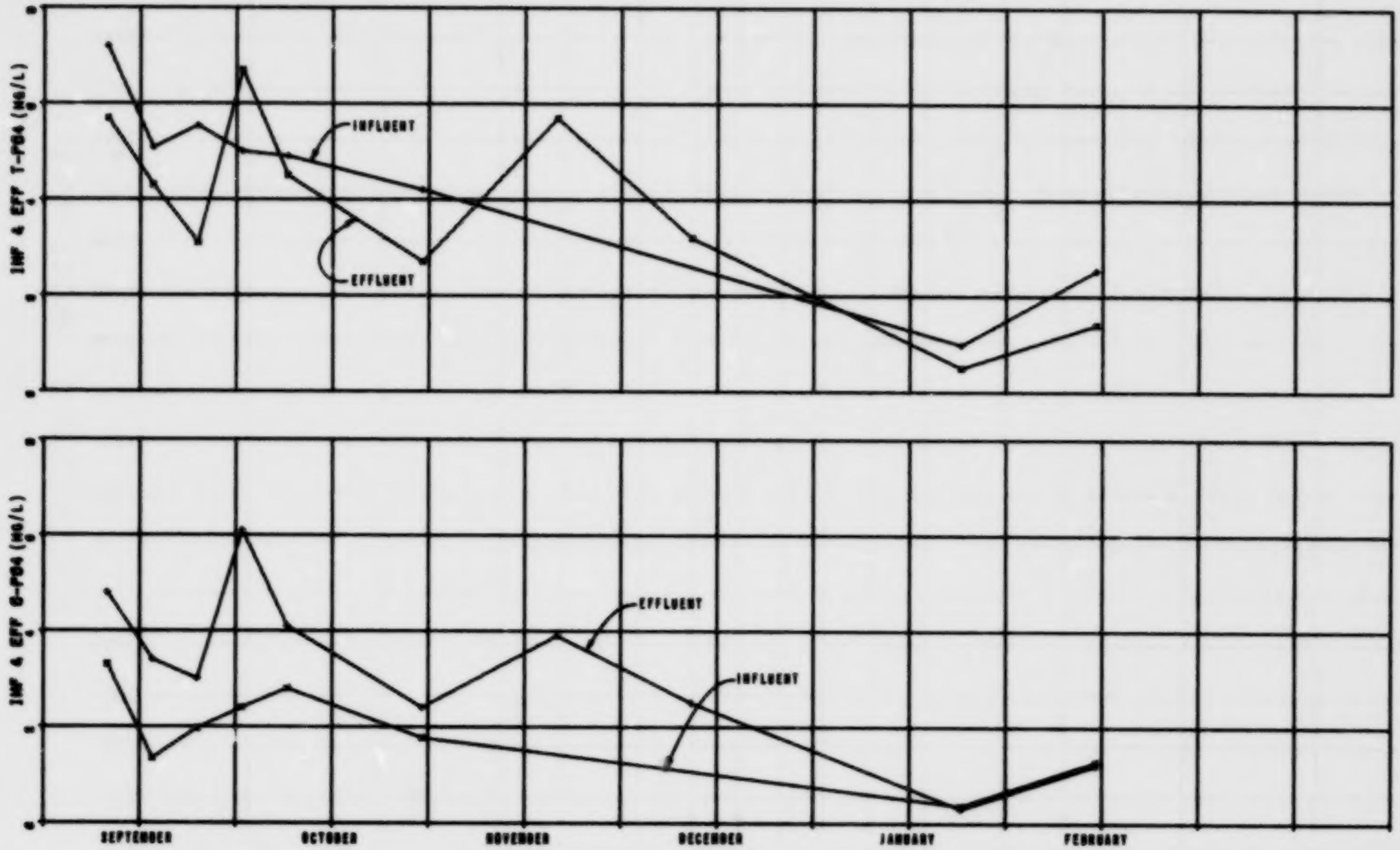

FIGURE 13

TOTAL AND ORTHOPHOSPHATE DATA FOR INFLUENT AND EFFLUENT FLOWS

C0002.7

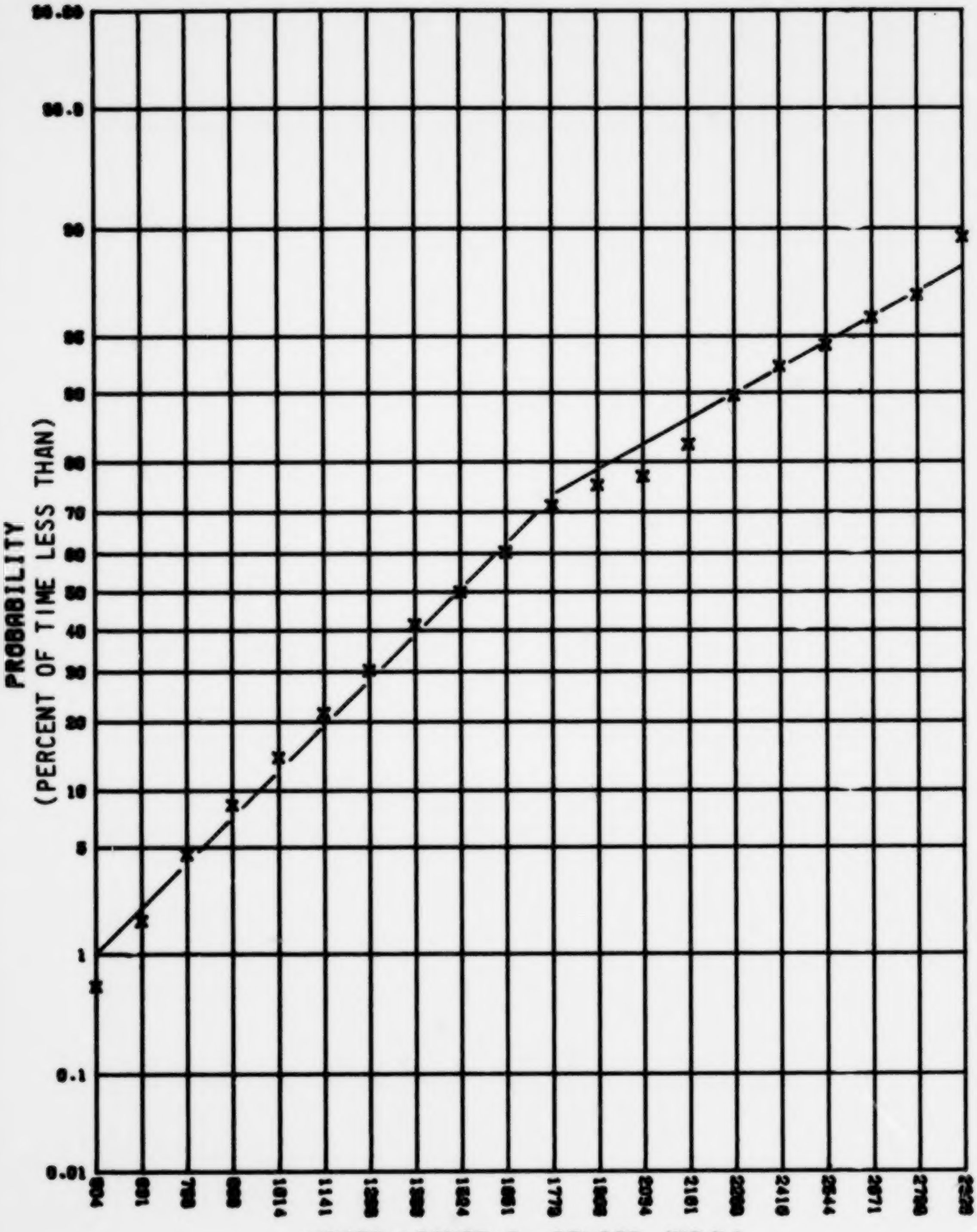

FIGURE 14

STATISTICAL ANALYSIS OF MIXED LIQUOR SUSPENDED SOLIDS DATA

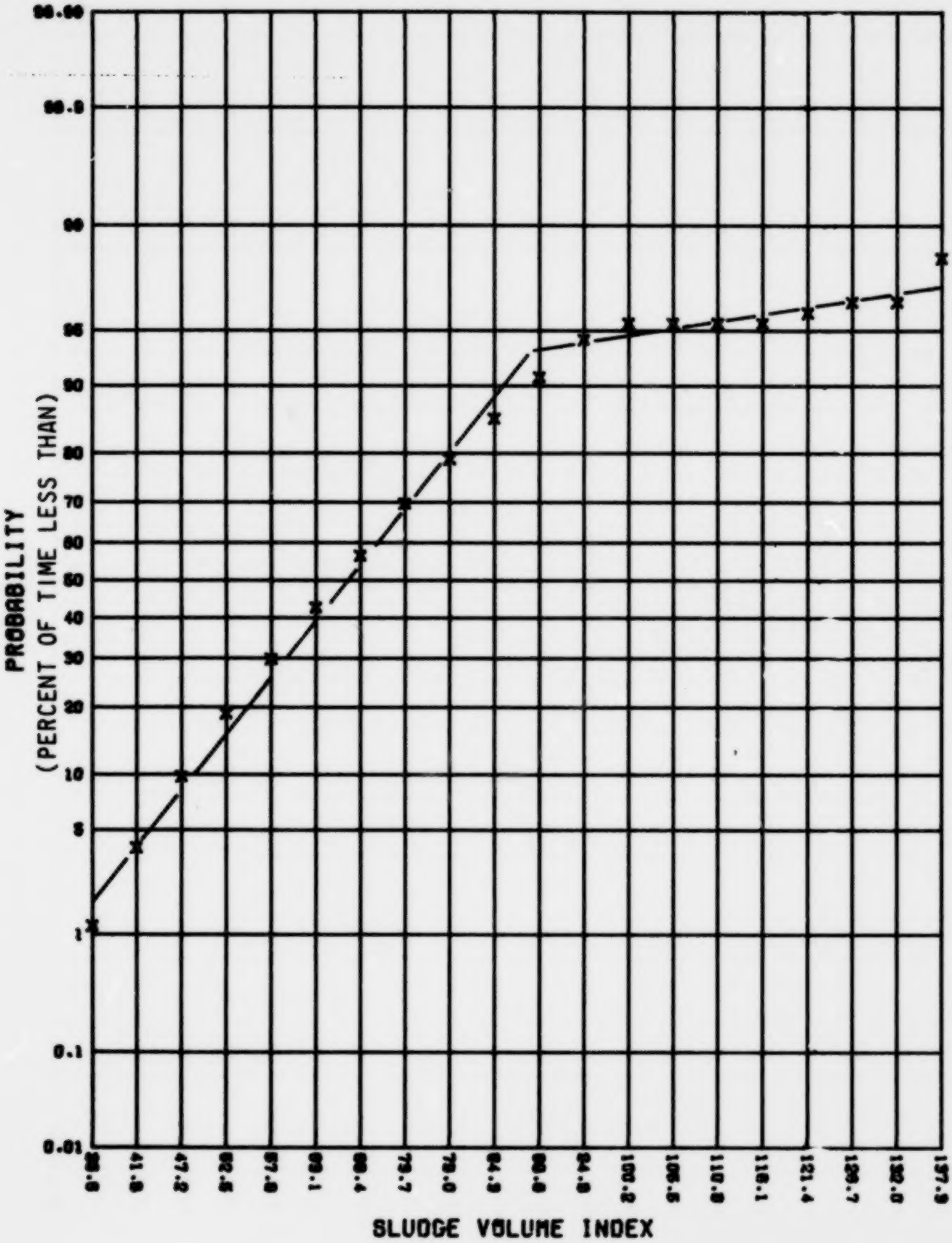

FIGURE 15

STATISTICAL ANALYSIS OF SLUDGE VOLUME INDEX DATA

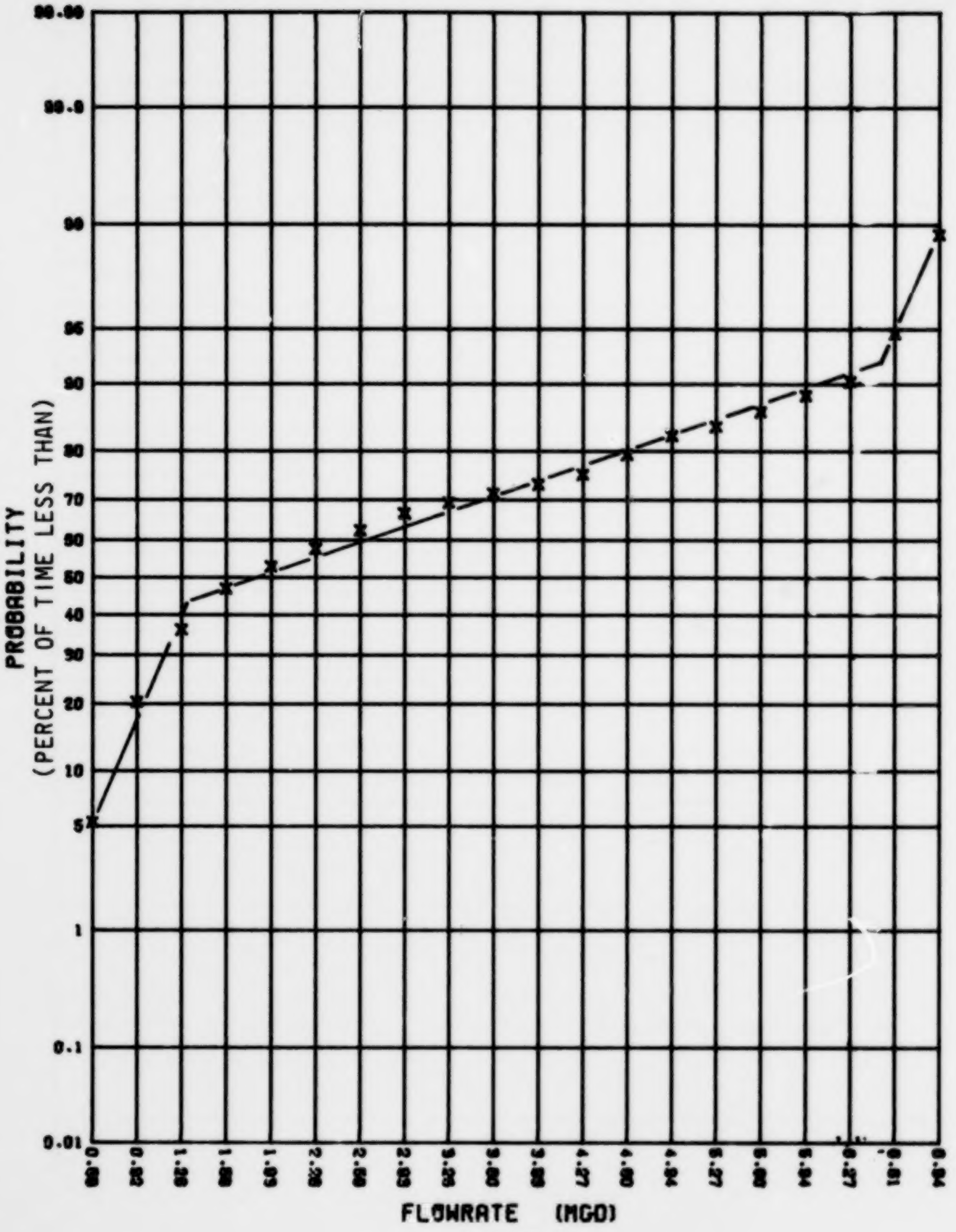

FIGURE 16

STATISTICAL ANALYSIS OF FLOWRATE DATA

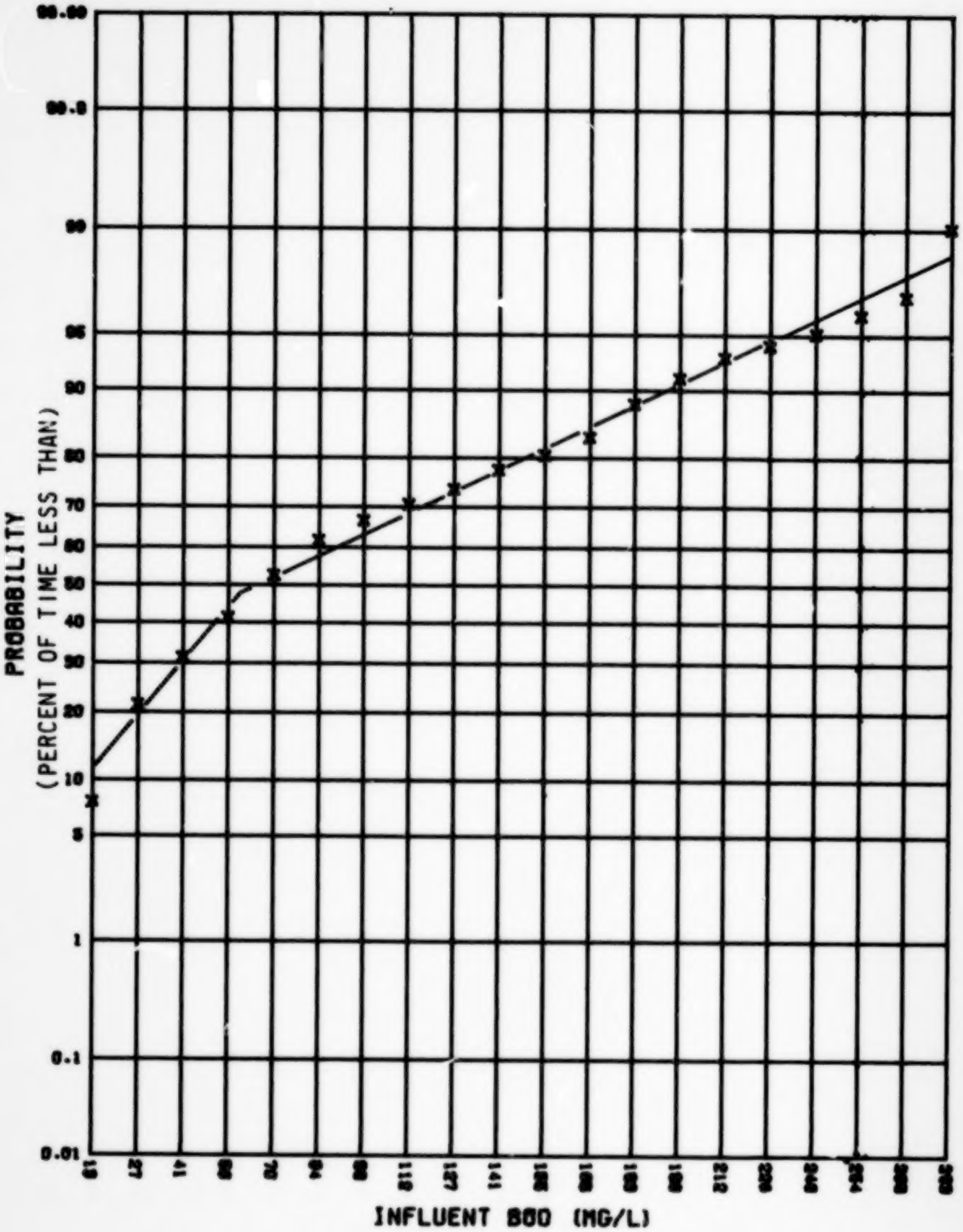

FIGURE 17

STATISTICAL ANALYSIS OF INFLUENT WASTE STRENGTH DATA

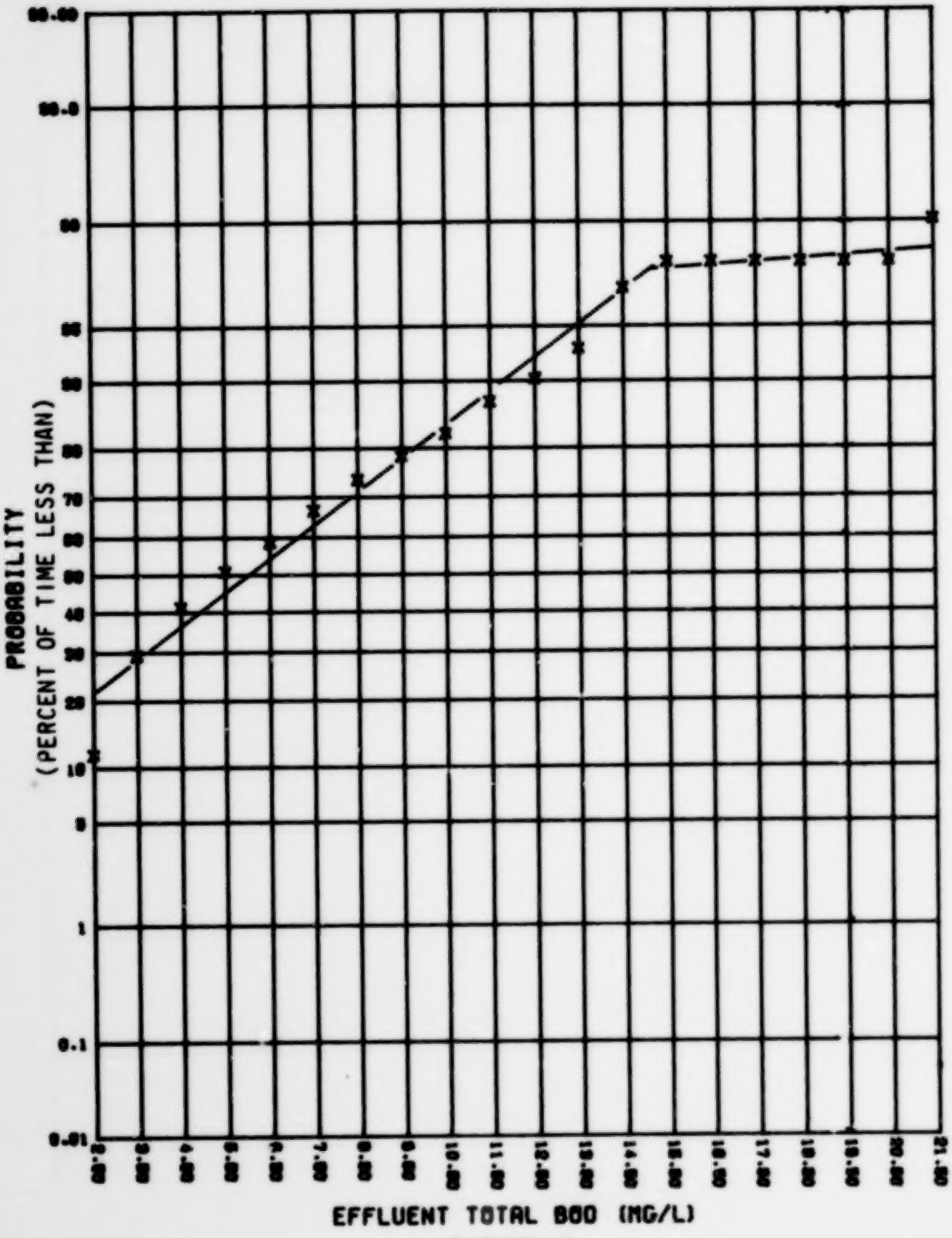

FIGURE 18

STATISTICAL ANALYSIS OF EFFLUENT TOTAL BOD DATA

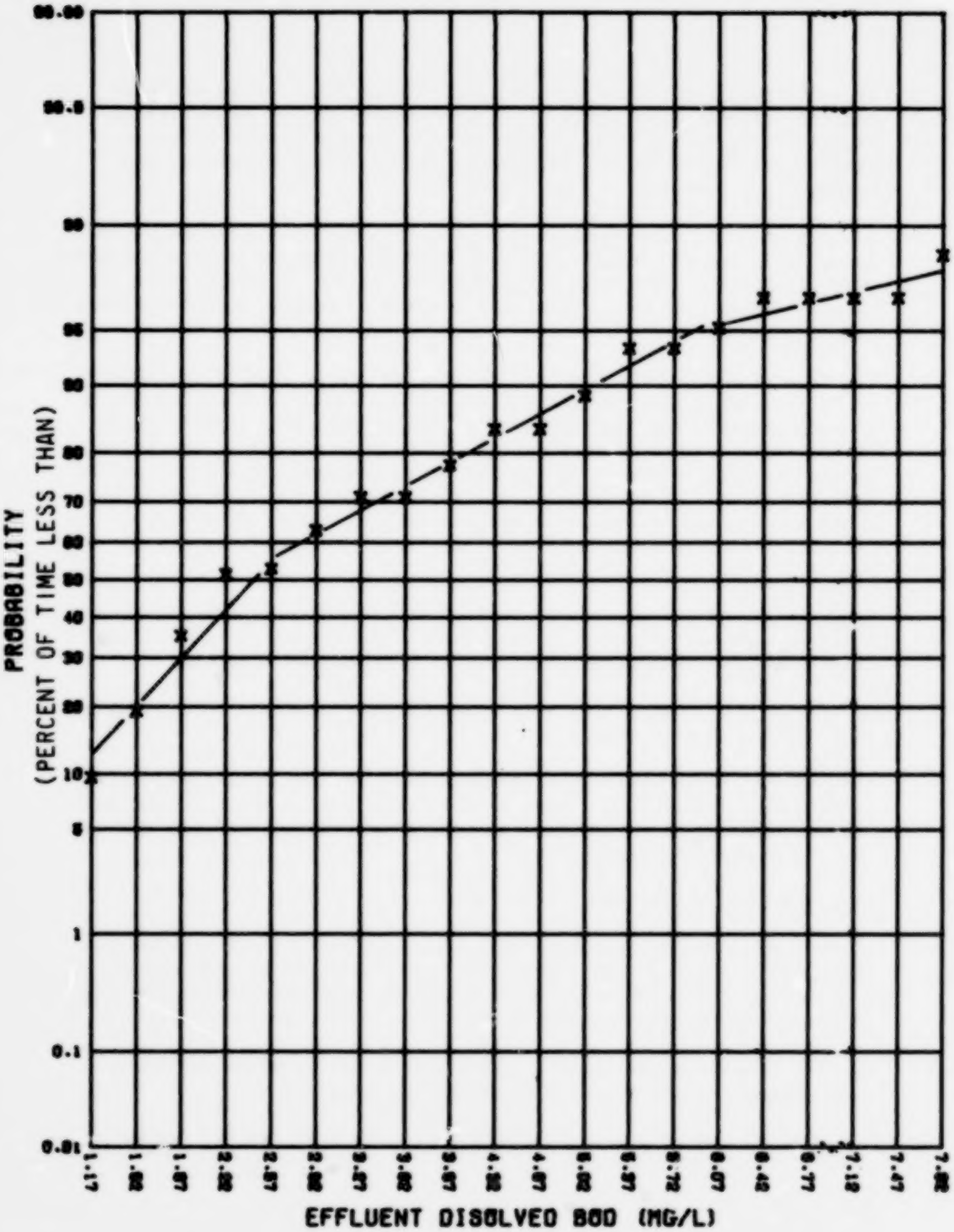

FIGURE 19

STATISTICAL ANALYSIS OF EFFLUENT DISSOLVED BOD DATA of waste solids produced per pound of BOD removed. This value is somewhat greater than would normally be expected for an activated sludge system because the lack of primary clarification allows a larger quantity of non-biodegradable solids to accumulate in the system.

No odor problems have been associated with the humus storage ponds during this period. This indicates that the digested sludge has been well stabilized. The drying characteristics of the sludge have not been determined as yet. This will be studied during the second half of the program.

The total construction cost for the Dallas plant, including engineering, was $506,300. Comparing this with a value of $950,000 for a 2.0 mgd conventional activated sludge plant obtained from Smith's* curves shows a capital cost saving of about 47 percent. Operation and maintenance costs at the Dallas plant for the six-months' period averaged about $20 per million gallons treated. This compares to a Smith curve value for a 2.0 mgd conventional plant of about $75 per million gallons treated, or a difference of approximately 70 percent.

Power cost, the largest single operation expenditure, has averaged about 20 percent less than anticipated. This is due to a low dissolved oxygen requirement resulting from small BOD loadings.

Operation labor costs have been minimized by operation on a 5-day per week, 8-hour per day basis.

The coliform data shows that adequate disinfection of the effluent has been provided. Dye tracer studies were run on the chlorine contact channel which showed that the actual detention time was greater than 90 percent of theoretical.

PRELIMINARY CONCLUSIONS

On the basis of the operation data obtained so far, the conclusions listed below can be made. However, these conclusions are subject to modification when the complete data has been obtained at the end of the demonstration program.

1. The process as designed is flexible enough to withstand high shock organic loads and abrupt changes in loading.

2. Elimination of primary clarification and grit removal causes no special operating problems.

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*Smith, Robert. Cost of Conventional and Advanced Treatment of Wastewaters. U. S. Department of the Interior, FWPCA, Cincinnati, Ohio. July 1968

3. The effluent quality has been consistently good despite wide variations in flow and organic loading.

4. Aerobic digestion is an adequate stabilization method for this combination of sludges.

5. A treatment system of this type can be constructed and operated at a substantial reduction in cost.

AEROBIC TREATMENT OF LIQUID FRUIT PROCESSING WASTE

by

Larry A. Esvelt*

INTRODUCTION

Subsequent to an order from the Washington Water Pollution Control Commission to remove 90 percent of BOD and suspended solids from processing effluents, Snokist Growers cannery undertook a two year construction and research program. The cannery which processes pears, peaches and apples as major products, obtained a research and development grant from the Federal Water Quality Administration to assist in the work. This paper summarizes the results of the study carried out.

The Snokist cannery had a processing capacity for approximately 250 tons per day of pears or peaches or approximately 100 tons per day of apples during the study. Their entire product was put out in cans and glass containers. Apple products include sauce, slices, and rings. The processing waste was greatest during the 2 1/2 to 3 months of pear and peach processing each fall when flows of about 2 mgd and BOD outputs (after screening) in excess of 20,000 pounds per day were experienced.

FACILITIES

The existing waste treatment facilities at the start of the study included vibrating screens with lift pumps, a 1.5 mg earth diked, asphalt lined lagoon with two 30 horsepower mechanical surface aerators, a small rectangular clarifier with hopper bottom, sludge recirculation pump and waste outfall to the Yakima river.

Prior to the first season of study a 6 million gallon earth diked basin was constructed and piped in parallel with the existing facility. This basin was lined with 0.020 inch PVC sheet and had installed four 60 horsepower surface aerators. Subsequent problems arose with the PVC liner when gas accumulated underneath it which carried it to the surface in bubbles. The bubbles were punctured as a temporary expedient to allow continued operation. Later, the basin was drained and the liner, which had had several seams split apart, allowing sludge underneath it, was repaired and covered with a layer of round river rock.

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* University of California, Berkeley. At the time of the study: Sanitary Engineer, Gray & Osborne, Consulting Engineers, Yakima, Washington.

Following the first season of study designs were drawn to add construction to make the system capable of meeting the State's standards. This consisted of clarification and sludge recycle for the large aeration basin, additional piping so recycled sludge could be reaerated in the small basin and additional aeration capacity for the large basin. A 90 foot diameter by 9 foot side depth clarifier with suction sludge removal was constructed. Two 1750 gallon per minute variable speed sludge recirculation pumps were installed and a 150 horsepower surface aerator was added to the large aeration basin. In addition a 30 foot diameter compressed air flotation sludge thickener was installed for wasting biological sludge.

A temporary laboratory was equipped for use prior to the completion of a new building. After completion the new lab was used to conduct all testing for the study.

OPERATION

During the first season of study the waste flow was split between the older small aeration basin and the newer basin, approximately 15 to 20 percent and 80 to 85 percent respectively, during pear and peach processing (Figure 1). The smaller basin with its clarifier was operated as an activated sludge treatment unit with biological sludge recycling. Considerable sludge went over the clarifier wiers and it was difficult to build up the mixed liquor solids level. The larger basin operated as a flow through unit or "completely mixed aerated lagoon" with biological solids passing out in the effluent. Nitrogen and phosphorus were added to the raw waste stream throughout the treatment.

At the beginning of the second study year the clarifier was not yet completed so the large basin once again acted as an aerated lagoon. After clarifier completion sludge was recirculated to the large basin to comprise an activated sludge treatment. During the last portion of the pear processing season sludge was recirculated through the small basin for reaeration (Figure 2). Nutrients were added throughout this season also.

Testing throughout the study was according to Standard Methods (1). Settleable solids were read following one hour settling time in a 1000 ml graduated cylinder. Suspended and volatile suspended solids were run using glass fiber filters (2). Total phosphorus was performed according to an alkaline ashing procedure (3). Oxygen depletion was measured for oxygen uptake determination with the use of a D. O. meter and stirred erlenmeyer flask (4).

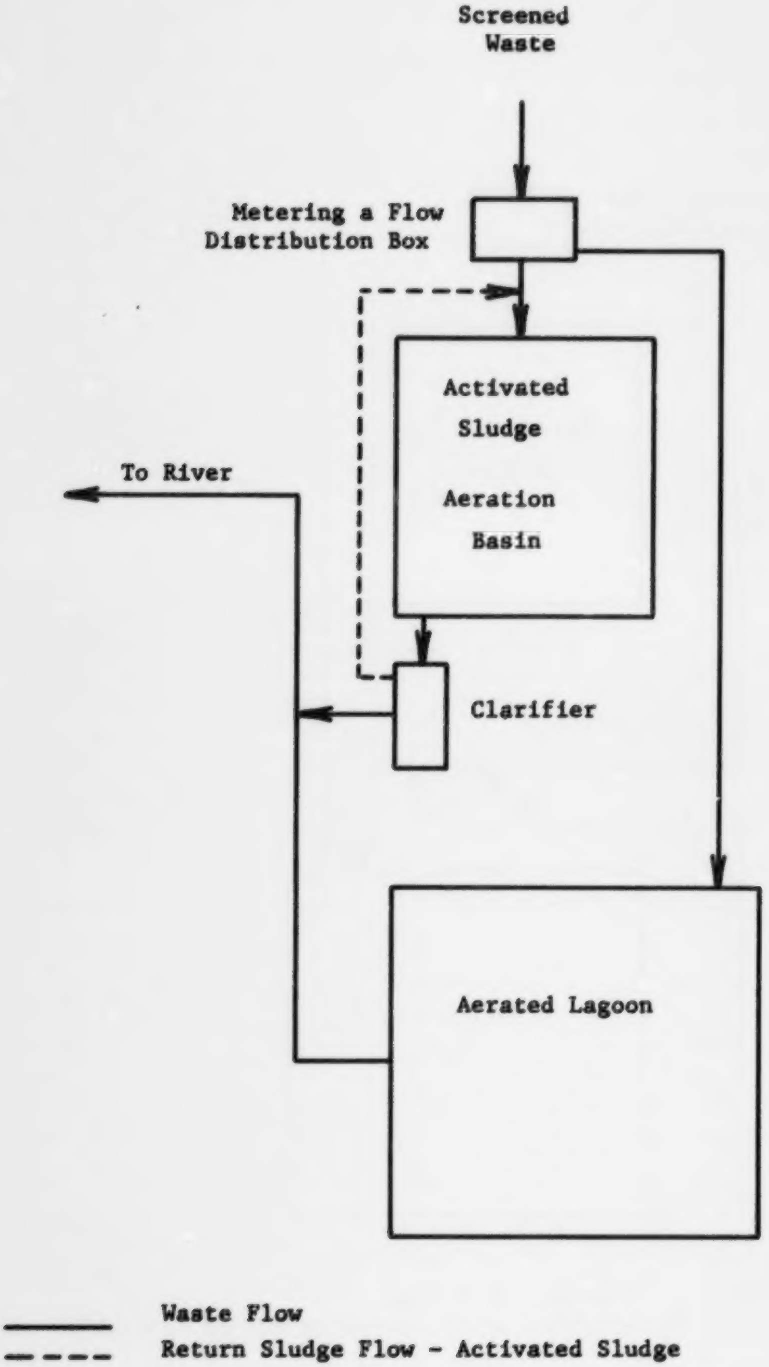
Screened
Waste
Metering a Flow
Distribution Box
Activated
Sludge
Aeration
Basin
To River
Clarifier
Aerated Lagoon
Waste Flow
Return Sludge Flow - Activated Sludge

Figure 1. SCHEMATIC FLOW DIAGRAM 1967-1968 PROCESSING SEASON

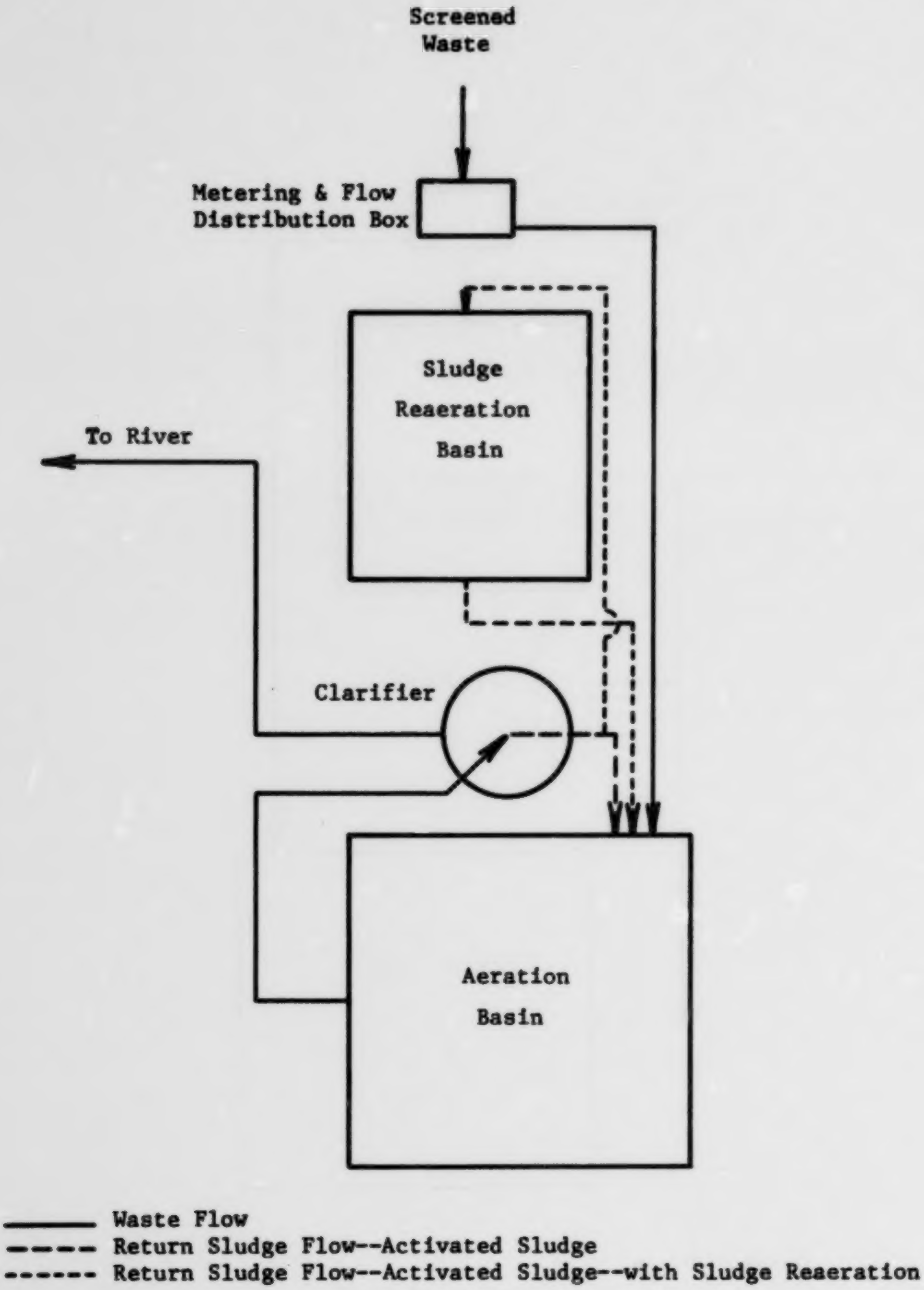
Screened Waste
Metering & Flow Distribution Box
Sludge Reaeration Basin
To River
Clarifier
Aeration Basin
——— Waste Flow
– – – – Return Sludge Flow--Activated Sludge
- - - - - - Return Sludge Flow--Activated Sludge--with Sludge Reaeration

Figure 2. SCHEMATIC FLOW DIAGRAM - 1968 PROCESSING SEASON

RESULTS

The operation of the treatment facilities during the two processing seasons definitely indicated that a good quality effluent is obtainable in the treatment of fruit processing waste. The three "methods" of treatment tried all demonstrated workability and confirmed that all three flow sheets were in reality just variations in configuration of a process in which the mechanism of organic removal follows the same laws of action. All three flow sheets, aerated lagoon, activated sludge and activated sludge with sludge reaeration developed a biological solids population in the aeration basin which acted on the waste according to the same principles. The significant differences in effluent quality were due to the amount of suspended solids (biological solids) contained therein.

Table 1 and Table 2 summarize the results experienced during the two years of operation of the treatment facilities. The values given are average for the treatment process and intervals indicated. As it can be seen from these tables BOD removal is consistently well above seventy percent during aerated lagoon operation and well above ninety percent when sludge was recirculated which allowed better solids removal due to the lower sludge organic loading.

Table 1. Treatment System Performance
1967-1968 Processing Season

	Screened Waste			Aerated Lagoon Effluent		
	Flow MGD	BOD mg/l	COD mg/l	BOD mg/l	COD mg/l	SS mg/l
Pear Proc.	1.03	2040	3050	370	1040	770
Peach Proc.	1.36	1810	2150	340		830
Apple Proc. (Nov. Dec.)	0.60	1230	1520	190	760	540
Apple Proc. (Jan. Feb.)	0.52	950	1400	110	620	470
				Activated Sludge Effluent		
Pear Proc.	0.21	2040	3050	250	490	375
Peach Proc.	0.30	1810	2150	360		370
Apple Proc. (Mar. Apr. May)	0.40	1390	1830	130	570	470

Table 2. Treatment System Performance
1968-1969 Processing Season

	Screened Waste			Effluent		
	Flow MGD	BOD mg/l	COD mg/l	BOD mg/l	COD mg/l	SS mg/l
Pear Processing Aerated Lagoon	1.48	2080	2870	460	1050	640
Peach Processing Aerated Lagoon	2.02	860	1510	115	710	520
Peach Processing Activated Sludge	2.02	860	1510	20	120	66
Pear Processing Activated Sludge	1.87	1600	2290	9	55	15
Pear Processing A.S. with Sludge Reaeration	1.58	2150	2910	4	23	6
Apple Processing Activated Sludge	0.43	1190	1500	5	28	11

DISCUSSION

Waste Characteristics

The screened waste strength and volume can be seen from Tables 1 and 2. The unit waste contribution as derived from waste testing and plant production records is shown on Table 3. Table 3 also contains the ratio of measured BOD to COD byproduct and the average nutrient available in the screened raw waste as a ratio to the BOD. As it can be seen by traditional standards the waste is nutrient deficient for biological treatment without nutrient addition.

Table 3. Unit Waste Contribution

Product	Flow*	COD**	BOD**
Pears	5800 gal/ton Raw Product	105#/Ton Raw Product	78#/Ton Raw Product
Peaches	7500 gal/ton Raw Product	98#/Ton Raw Product	66#/Ton Raw Product
Purple Plums	7000 gal/ton Raw Product	95#/Ton Raw Product	64#/Ton Raw Product
Tomato Juice	3200 gal/ton	Negligible compared to concurrent products being run	
Apples	8200 gal/ton Raw Product	71#/Ton Raw Product	53#/Ton Raw Product

* gal per ton of raw product
** lbs per ton of raw product

Product	$\frac{BOD}{COD}$	$\frac{P}{BOD}$	$\frac{N}{BOD}$
Pears	0.74	0.0012	0.006
Peaches	0.67	0.0027	0.011
Apples	0.75	0.0010	0.0023

Cost of Treatment

The $543,000 total cost of construction of the facilities can be broken down by treatment components and amortized to arrive at unit costs which when added to O & M costs and divided by the waste load become unit costs of treatment (4). These costs shown in Table 4 reflect the waste levels and season length experienced. The raw COD and BOD received for treatment each season was approximately 2.0 and 1.5 million pounds, respectively.

Table 4. Estimated Unit Costs of Treatment

	Aerated Lagoon	Activated Sludge	
		Without Sludge Reaeration	With Sludge Reaeration
Construction Costs	$205,000	$470,000	$557,000
Annual Cost of Construction (20 years @ 7% interest)	19,400	44,400	52,600
Power Cost	7,000	10,000	10,000
Nutrient Chemicals	10,500	10,500	10,500
Operation and Supervision	6,000	12,500	12,500
Maintenance Labor & Materials	1,500	2,000	2,000
Laboratory Supplies	1,500	2,500	2,500
Major Repairs and Improvements	3,000	5,000	5,000
Annual Cost of Treatment	$ 48,900	$ 86,900	$ 95,100
Assumed % COD Removal	70%	90%	90%
Cost per #COD Removed	$ 0.035	$ 0.048	$ 0.053
Assumed % BOD Removal	80%	95%	95%
Cost per #BOD Removed	$ 0.041	$ 0.061	$ 0.067

Substrate Removal

The removal of organic substrate (soluble BOD or COD) by a biological population is presently generally believed to follow a kinetic model similar to the Michaeles - Menten equation for enzyme reactions (5). The use of this equation (equation 1) is dependent upon the assumption that the aeration basin functions closely as a completely mixed basin. Volatile suspended solids is assumed to represent a measure of active biological mass.

$$R = \frac{Fs}{S+s} \tag{1}$$

R = Substrate removal rate; mg BOD, COD/mg MLVSS-day
F = Maximum removal rate
S = Substrate concentration at R = 1/2 F
s = Substrate concentration; mg BOD, COD/1

Since S, is usually large compared to s in a normally operating treatment system, where R is normally much less than one, this equation can be reduced to a first order expression such as equation (2).

$$R = fs \tag{2}$$

f = First order removal rate constant or "removal coefficient";

$$\frac{\text{mg BOD or COD removed}}{\text{mg MLVSS-day-mg/1 BOD or COD}}$$

The data derived from this study using BOD as the substrate is presented on Figure 3, with data corrected to 20°C. A straight line corresponding to equation (2) is plotted through the data. Considerably more data was available for COD removal and substrate concentration than BOD. This data was plotted by temperature ranges and the coefficients resulting from each group of data is plotted against its mean temperature on Figure 4. As it can be seen the points fit closely the line described by equation (3). The correction factor found here was used to correct the BOD removal data for construction of

$$f_T = 0.017 \times 1.16^{T-20} \tag{3}$$

f_T = COD removal coefficient at T °C

Figure 3. Figure 3 then yielded the coefficient for BOD removal at 20°C and equation (3a) is derived.

$$f_{T_{BOD}} = 0.068 \times 1.16^{T-20} \tag{3a}$$

$f_{T_{BOD}}$ = BOD removal coefficient at T °C

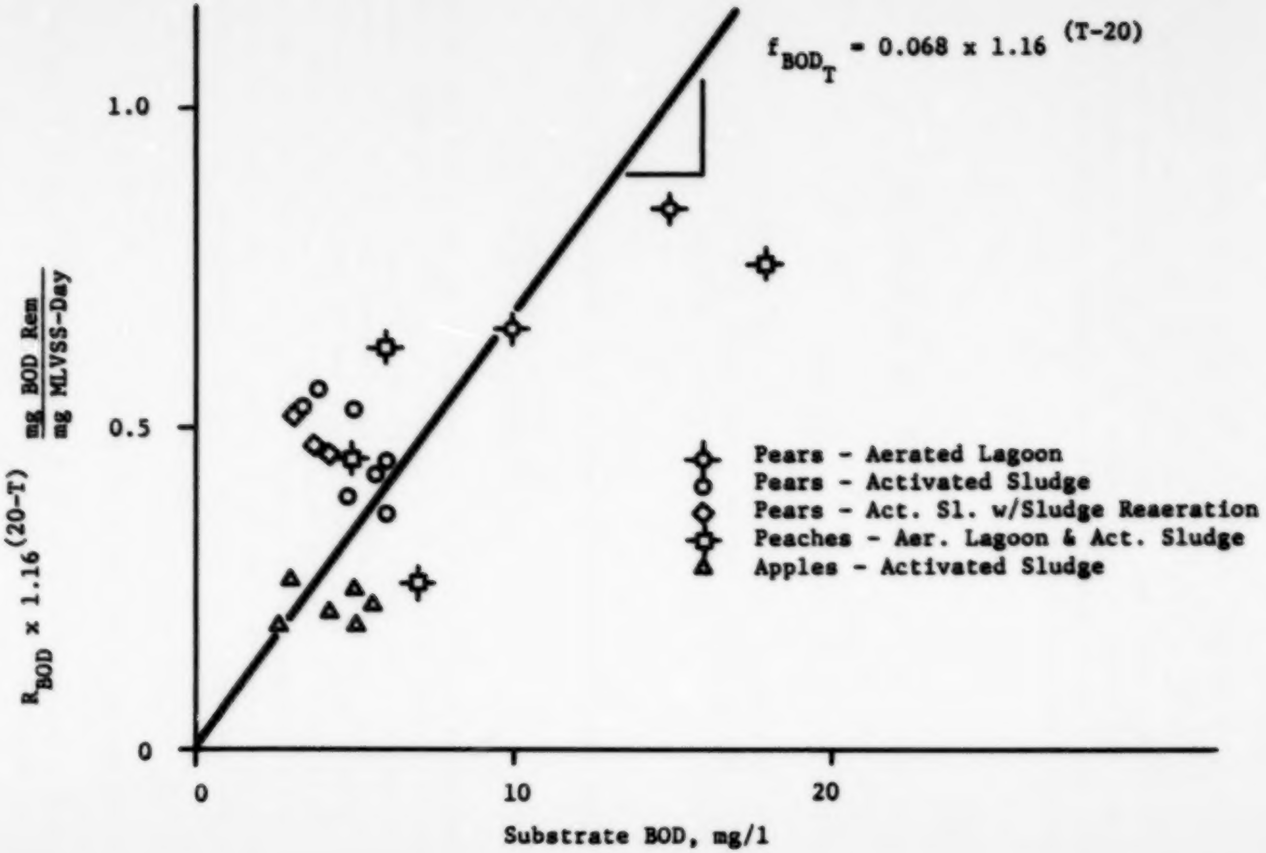

Figure 3. BOD REMOVAL RATE VS CONCENTRATION AT 20°C

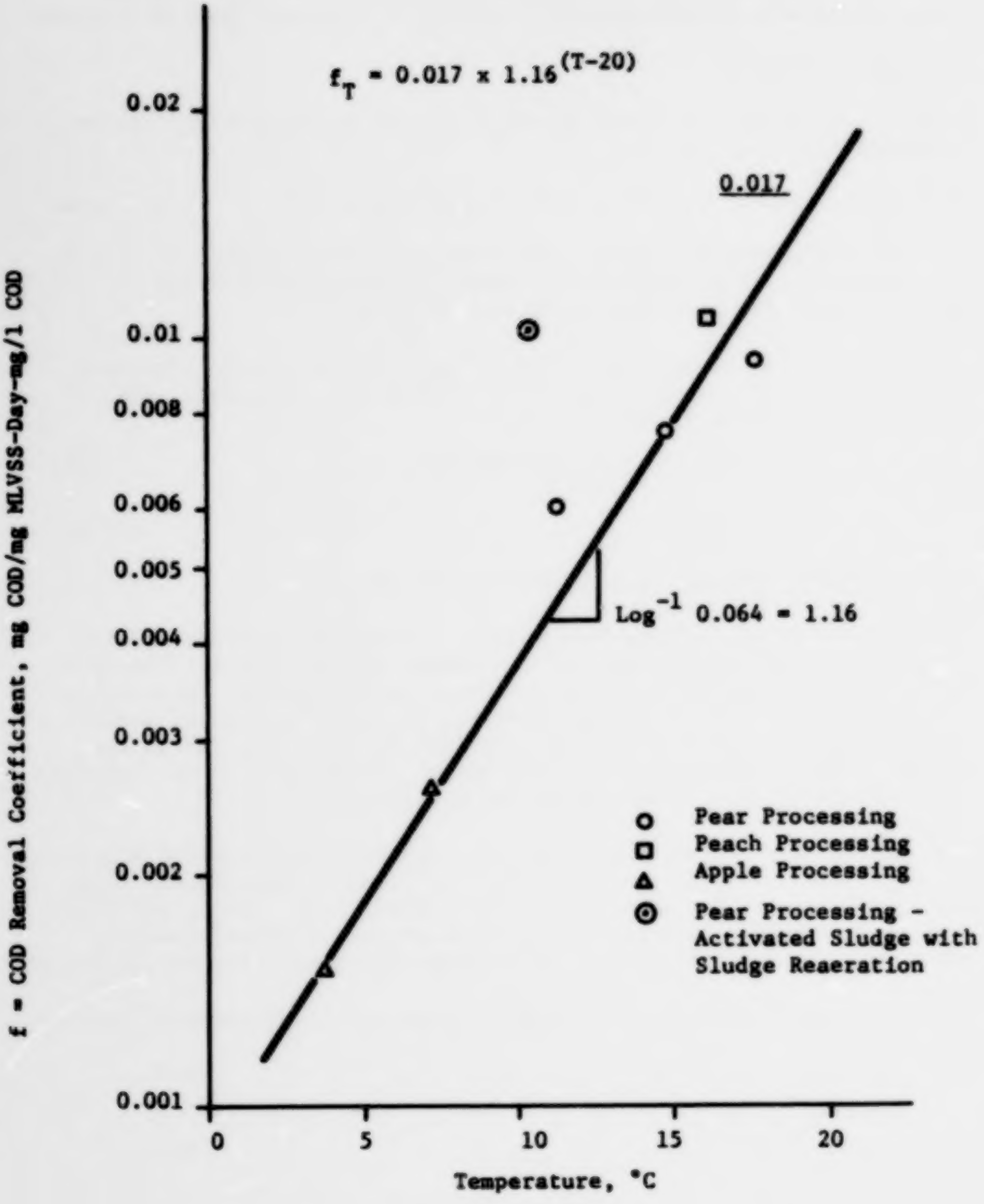

Figure 4. COD REMOVAL COEFFICIENT VS TEMPERATURE

There did not appear to be variations in "f" according to product being processed but data scatter could have obscured small deviations.

Biological Growth

A material balance of MLVSS across a completely mixed basin yields equation (4). [5] [6] [7]

$$\text{Net Sludge Growth} = c(\text{BOD or COD removed/day})k \cdot \text{MLVSS} \qquad (4)$$

c = Yield coefficient, mgVSS formed/mgBOD or COD removed
k = Endogenous respiration rate, mgVSS destroyed/mgMLVSS-day
MLVSS = Mixed liquor volatile suspended solids

Equation (4) can be divided by the mixed liquor volatile suspended solids and since equation (5) is the definition of removal rate, equation (6) can be formed.

$$R = \frac{\text{BOD or COD removed/day}}{\text{MLVSS}} \qquad (5)$$

$$G = cR-k \qquad (6)$$

G = Net sludge growth rate, mgVSS/mgMLVSS-day

MLVSS here refers to the total weight of volatile suspended solids in the treatment system and the net sludge growth rate (G) consists of volatile suspended solids accumulated in the system, those which are wasted from the system as carryover in the effluent and those intentionally removed by wastage, divided by the total VSS in the system. The reciprocal of the net sludge growth rate is the "sludge age" of the biological solids in the system.

The data gotten during this study were separated and plotted according to major product being processed and according to temperature range. Net sludge growth was plotted vs. COD removal rate. The yield coefficient varied with product being processed but remained constant with temperature change. The yield coefficients obtained are as follows:

Product Being Processed	mgVSS/mgCOD Removed	mgVSS/mgBOD Removed
Pears	0.49	0.66
Peaches	0.46	0.69
Apples	0.57	0.76

c = yield coefficient

The endogenous respiration rate obtained from the zero removal rate intercept on the sludge growth axis (negative) varied with temperature. The values obtained are plotted on Figure 5 vs. temperature. It can readily be seen that the points very nearly fall on the line described by equation (7).

$$k_T = 0.115 \times 1.14^{(T-20)} \qquad (7)$$

k_T = Endogenous respiration rate at temperature T,°C

On Figure 5 the next to highest point was obtained from peach processing data while the lowest was from apple processing data so apparently no difference in endogenous respiration rate exists between sludge developed on pear, peach or apple processing waste. There was no difference in growth or respiration characteristics between sludge developed in aerated lagoon treatment and activated sludge.

Oxygen Requirements

The oxygen requirements for an aerated system depend upon the amount of organic matter removed from the waste stream and on the amount of volatile suspended solids in the aeration system as described by equations (8) and (9). [5] [6] [7]

$$O_2 = a \cdot \text{BOD or COD removed} + b \cdot k \cdot \text{MLVSS} \qquad (8)$$

$$O_2/\text{MLVSS} = a \cdot R + b \cdot k \qquad (9)$$

In these equations "k" is the endogenous respiration rate, "R" is the substrate removal rate and "a" and "b" are constants.

The oxygen uptake rate studies from individual days resulted in data for various substrate removal rates and at various temperatures. Using the temperature correction factor for the endogenous respiration rate, these individual data points were corrected to 20°C and plotted on Figure 6. From Figure 6 the constants a and b were obtained.

a = 0.34mgO_2 required/mgCOD removed
a = 0.46mgO_2 required/mgBOD removed
b = 1.2mgO_2 required/mgVSS destroyed by endogenous respiration

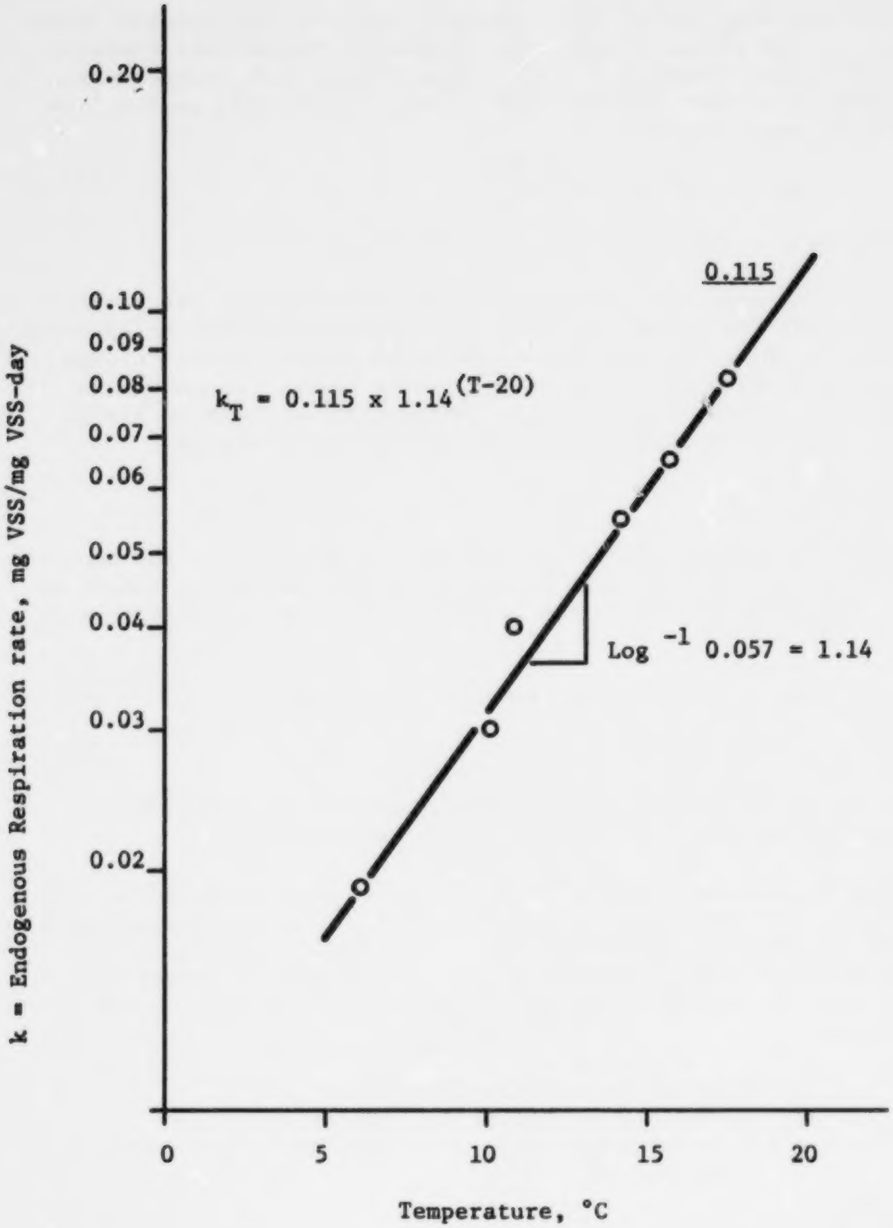

Figure 5. ENDOGENOUS RESPIRATION RATE VS TEMPERATURE

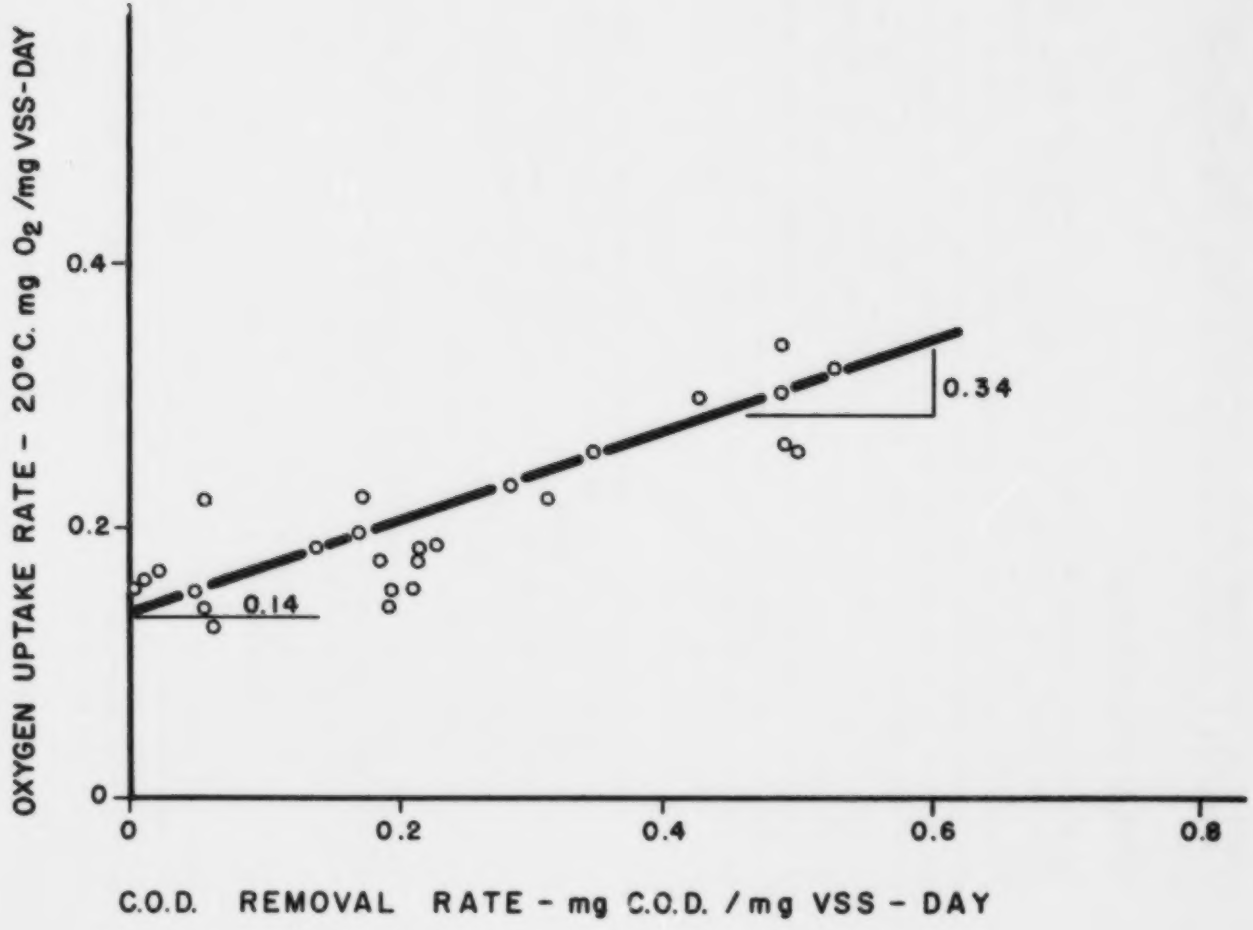

Figure 6. OXYGEN UPTAKE RATE VS COD REMOVAL RATE AT 20°C

Using the constants obtained and loadings experienced, the oxygen supplied by the surface aerators was computed. They were capable of supplying 2 pounds of O_2 per horsepower hour with a residual of one mg/l.

Sludge Characteristics

The biological sludge developed on the fruit processing waste was quite different from sludges normally found in domestic waste treatment plants. The solids were about 90 percent volatile and exhibited a very slow settling velocity at high concentrations. Figure 7 shows sludge settling curves for various dates during the 1968 season. The COD removal rate is given on each plot along with the mixed liquor suspended solids on that date. With the exception of 9-4-68 it can be seen that settling improved with a lower removal rate. On 9-4-68 the system was still operating as an aerated lagoon. The supernatant of the settled sample remained quite cloudy indicating a large portion of the solids did not settle and demonstrated what has been termed "deflocculated" sludge [8]. The samples other than 9-4-68 were from the system when sludge recirculation from the clarifier was being practiced and very clear supernatant was experienced both from the settled samples and clarifier.

The clarifier for this treatment system was designed for an overflow rate of 400 gallons per day per square foot after reviewing the settling data from the first year of operation. It operated at about this value or less throughout the study. Solids removal was excellent with a very clear effluent. Return sludge concentrations exceeded 6000 mg/l at times and MLSS got as high as 3500 mg/l. During the 1968 season MLSS got up to 5000 mg/l [10].

Figure 8 shows the COD and BOD of the biological sludge as mgCOD or BOD per mgVSS plotted against COD and BOD removal rate. The plot yields the relationship:

$$\text{mgCOD/mgVSS} = 1.39$$
$$\text{mgBOD/mgVSS} = 0.3 + 0.28 \times \text{BOD removal rate}$$

Figure 9 shows the organic nitrogen and phosphorus content of the sludge measured as volatile suspended solids. The lowest four points of data for nitrogen and lowest two points of data for phosphorous were gotten when the residual dissolved nutrient was zero so deficiency could not be ruled out. It must be concluded that

$$\text{Organic N/mgVSS} = 0.087\ \text{mg}$$
$$\text{Organic P/mgVSS} = 0.016\ \text{mg}$$

Process Control

Control of the treatment process is mandatory for achievement of consistent and reliable treatment results. The maintenance of a

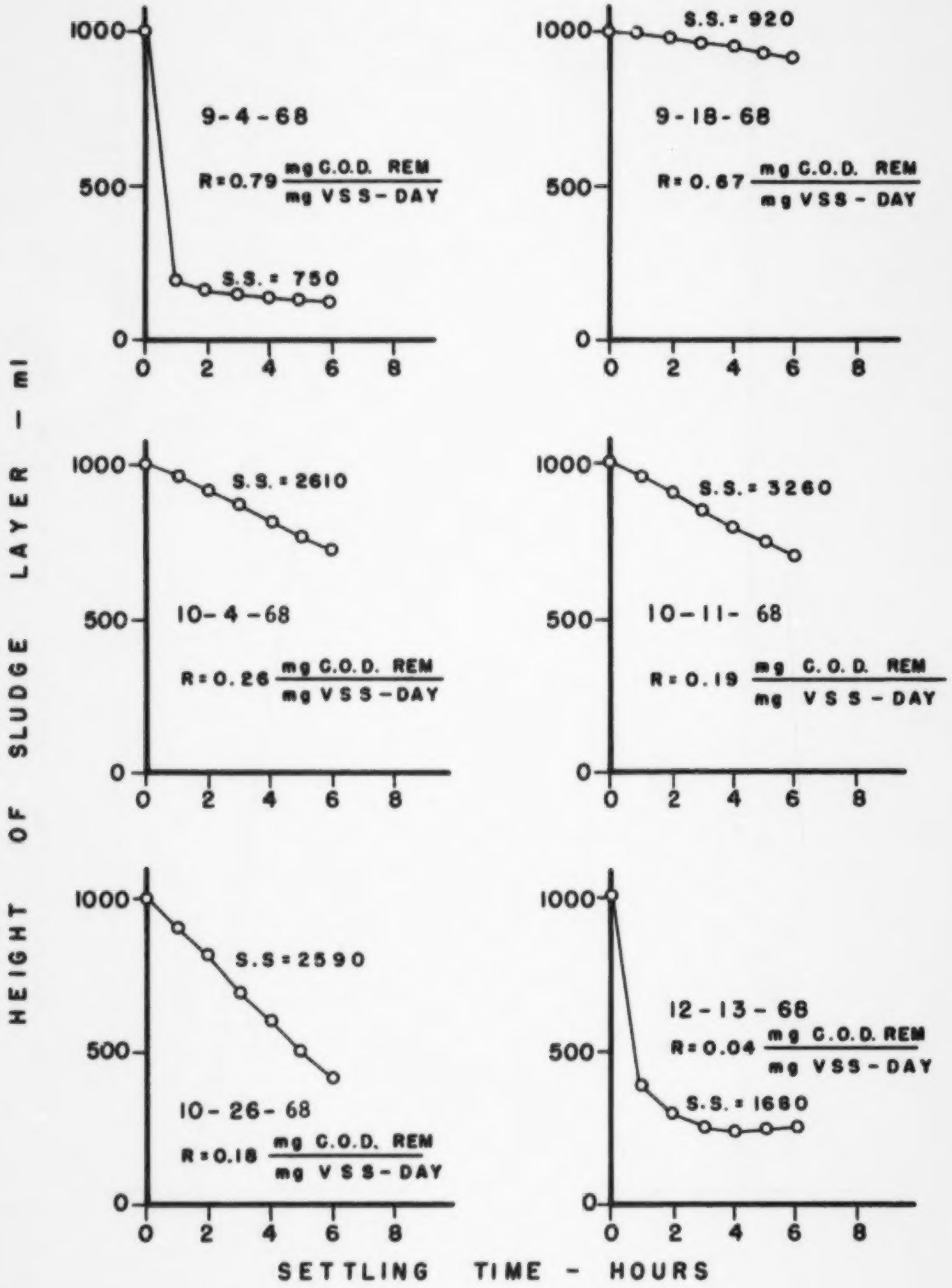

Figure 7. SETTLING CURVES OF AERATION BASIN SUSPENDED SOLIDS

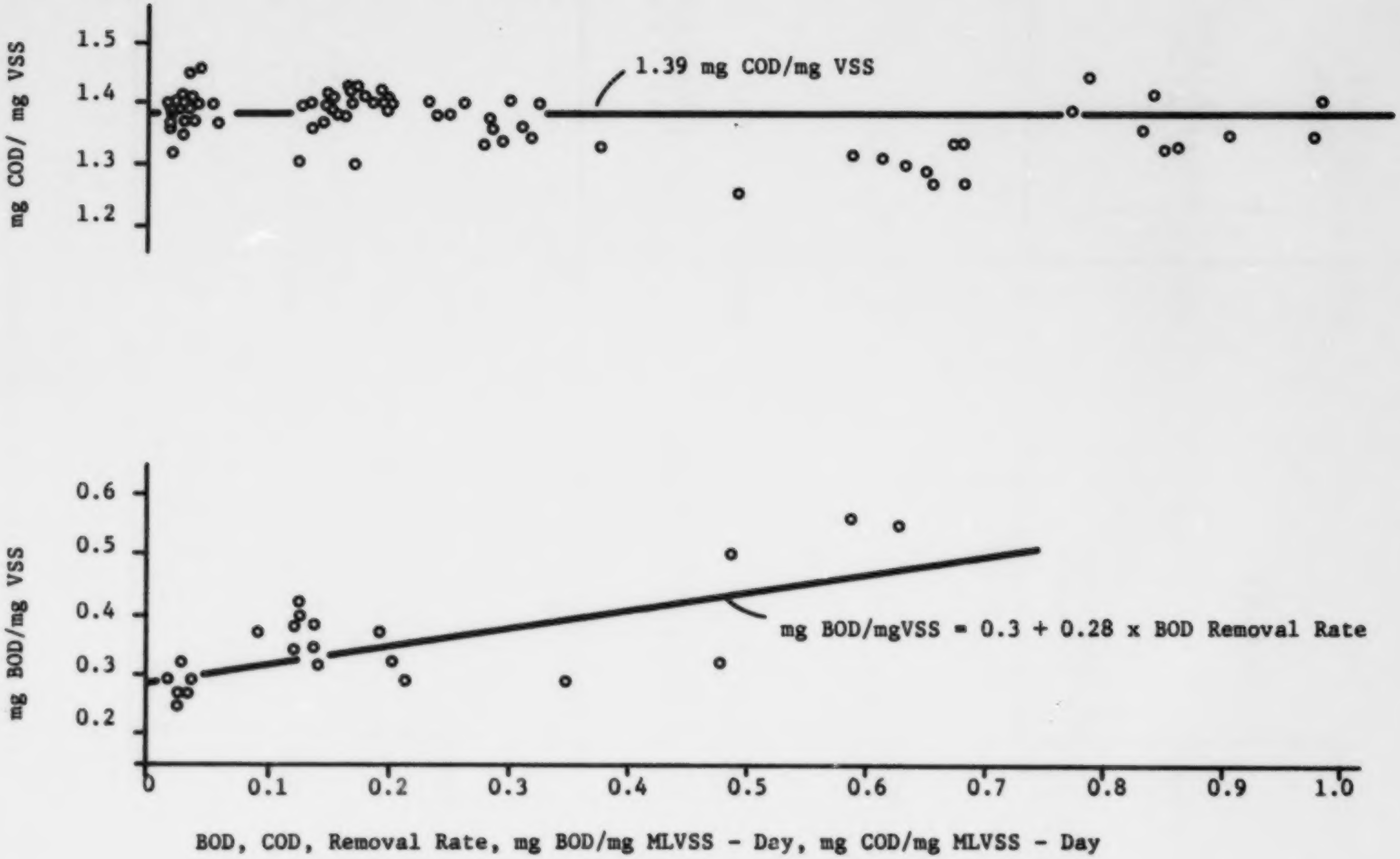

Figure 8. BOD, COD EQUIVALENT OF VSS

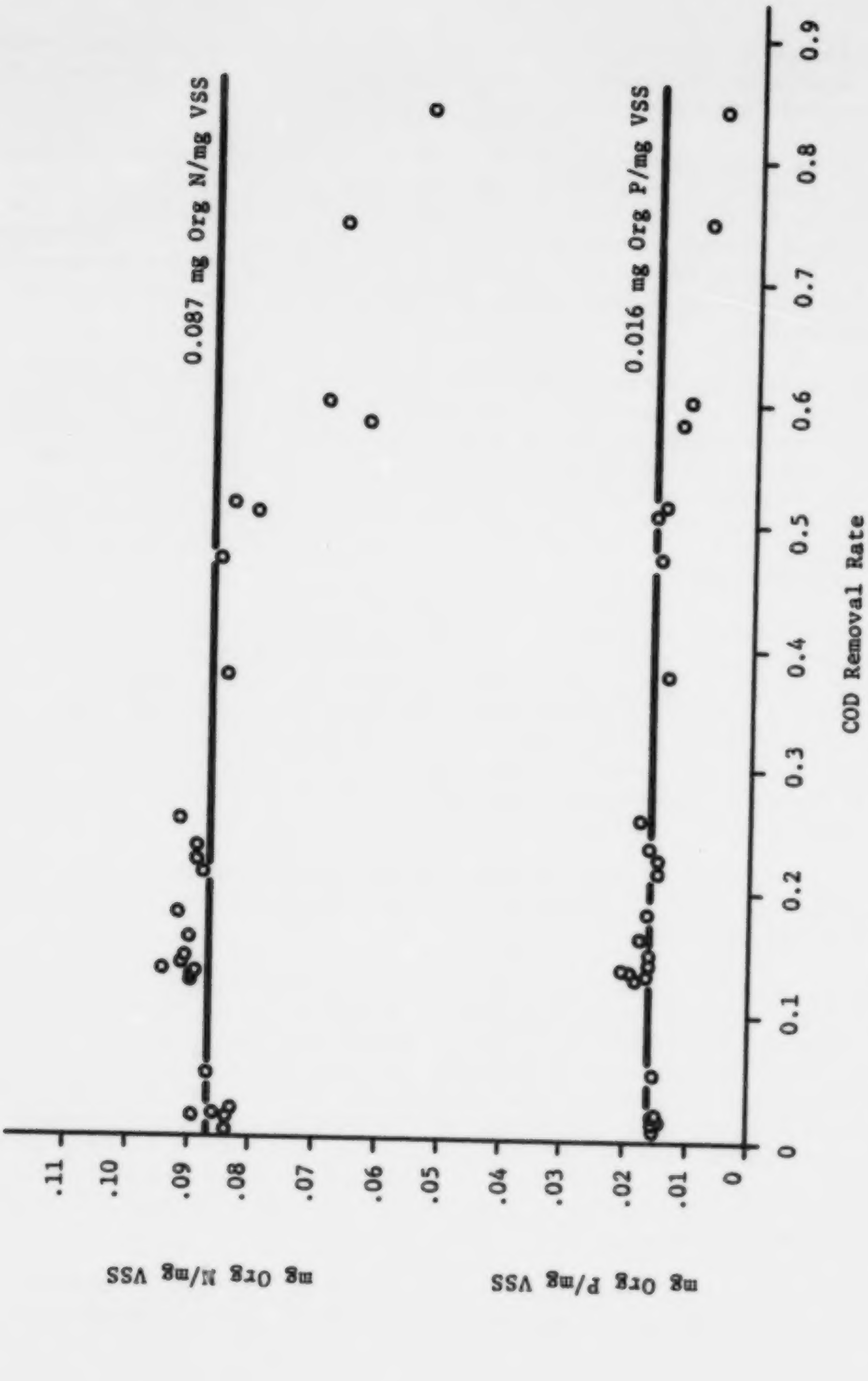

Figure 9. NITROGEN AND PHOSPHORUS CONTENT OF BIOLOGICAL SLUDGE

high degree of treatment, uninterrupted by conditions of upset which are capable of affecting the effluent is necessary for assurance of undamaging influence on the receiving water.

The pH in these treatment units remained virtually constant at near 7 throughout both processing seasons. The nearly completely mixed condition of the aeration basins and the buffering provided by the biological system prevented acid or alkaline conditions from occurring. The influent pH varied from 6 to 8 during pear and apple processing and from 10 to 11 during peach processing due to the alkaline peel operation.

Nutrient feeding is necessary with this waste to achieve satisfactory biological treatment. The total nutrient (nitrogen and phosphorus) requirement is the amount necessary to supply the biological yield at the percentage of the constituent incorporated into the MLVSS. Nitrogen and phosphorus are released by the MLVSS through organism breakdown by endogenous respiration but it has been observed that about 20 to 25 percent of the amount in the respired sludge is not released [9].

Nutrient feeding is normally related to the waste constituents (COD or BOD) and others have given desirable ratios for N and P to COD or BOD. Taking the N and P content of MLVSS found and the yield coefficient a maximum requirement per amount of substrate removed can be obtained. The total nutrient requirement could then be reduced by the amount being released per day from organism destruction by endogenous respiration, which is governed by substrate removal rate and temperature.

A short run at nutrient deficient conditions demonstrated impairment of substrate removal efficiency and biological solids (MLVSS) which exhibited no settling.

Startup of the treatment system results in a lower quality effluent for about a week. Initially the clean water-filled basin dilutes the wastes. As solids build up a portion are lost over the clarifier wier. By the end of one week the system has usually reached stability and even during the week of startup the effluent BOD and COD are considerably lower than in the influent. Temporary shutdowns of waste feed do not cause upsets in the system so long as the basins are continually aerated. Shutdowns of a week seem to be permissible. Changes in product being processed did not adversely affect the treatment.

Control of solids level must be practiced in the form of solids wasting to avoid exceeding the capacity of either 1) the aeration system to support them or 2) the clarification-sludge return system capacity for solids removal and return. In this system solids are wasted to a flotation thickener for subsequent land disposal.

Operation of the system in extremely cold weather can lead to problems. During late December, 1968, and January, 1969, sub-zero temperatures were experienced. No processing was occurring and the aeration basin sub-cooled and subsequently froze over. Prior to their shutdown the aerator platforms had accumulated a considerable amount of ice. It was not determined whether the aerators could have been kept in operation if run continuously. Processing operations did not begin until the basin had thawed.

Sludge Thickening

Sludge disposal is a major problem from an operation of this type. A flotation thickener with pressurized recycle was installed for this facility.

During the operating season testing done on the thickener indicated that the float concentration would not exceed about 2 percent D.S. During special testing performance of sludge thickening was evaluated [11] during a period when BOD rate was about 0.4 day $^{-1}$ and the volatile content of the solid about 87 percent. Air:solid ratio was about 0.6 and the feed sludge was 6000 to 7000 mg/l solids.

Solids Loading lb/hr./ft^2	Hydraulic Loading gpm/ft^2	Float Solids %
0.4	0.5	2.5
0.4	0.6	2.1
0.5	0.43	2.1
0.65	0.6	1.9

For a comparison with this sludge thickening performance, the Selah, Washington municipal sewage treatment plant receives from 30 to 70 percent of its BOD load as screened fruit processing. The combined waste does not receive primary clarification and is treated by activated sludge process. Waste activated sludge is also thickened by compressed air flotation. During 1969 the sludge thickened here averaged 3.8 percent D.S. without significant fluctuations between active and less active industrial season [12]. The BOD removal rate was similar to that at Snokist but sludge volatility ranged from 66 to 76 percent volatile. Solids thickening rate ranged from less than one to greater than two pounds per hour per square foot and hydraulic loading rate ranged from 1.35 to 2 gpm per square foot without seeming to affect the solids concentration. It would appear that the domestic component beneficially affects fruit processing waste activated sludges thickening characteristics even though other influences were undoubtedly present.

Summary and Conclusions

In summary, the conclusions drawn from the study of treatment of fruit processing wastes are as follows:

1. Activated sludge or contact stabilization treatment of fruit processing waste at low rates (below 0.4 mgCOD removed per day per mgMLVSS) will provide greater than 90 percent removal of organic load and removal of solids from the effluent. The activated sludge process does as adequate a job as contact stabilization and would be recommended because of requiring less facilities and thereby lower cost.

2. Aerated lagoon treatment can provide greater than 70 percent BOD removal but suspended solids remain in the effluent and are the principle source of effluent BOD and COD. This treatment is considerably less expensive and is recommended if the effluent quality can be tolerated.

3. "Completely mixed" aeration basins provide effective buffering to avoid pH fluctuations.

4. Final clarification for activated sludge or contact stabilization is successful at low surface loading rates (below 400 gallons per square foot per day), made necessary by the slow-settling sludge developed, and with vacuum type sludge removal.

5. Nutrient addition is necessary to achieve successful treatment. Nutrient savings can be made by increasing the amount of biological sludge in the system, thus decreasing the waste loading rate on the sludge. This allows a greater destruction of sludge by endogenous respiration which returns nutrient to the system and cuts down the amount necessary to add. Activated sludge or contact stabilization treatment is necessary to accomplish this.

6. Surface aerators accomplished adequate mixing at 0.3 hp/1000 cubic feet and provided 2 pounds of oxygen transfer per horsepower hour under operating conditions.

7. PVC sheeting is a suitable basin lining material provided adequate diligence is expended in assuring sound field welds at all joints. It is recommended that the bottom be covered with sufficient material to prevent it from floating even if gas should accumulate beneath it.

8. The biological sludge developed seemed to be independent of the type of fruit processing waste and

- a. about 90 percent volatile
- b. settled very slowly
- c. settling improved at low COD and BOD removal rates
- d. mg COD/mg VSS = 1.39
- e. mg BOD/mg VSS = 0.3 + 0.28 x BOD removal rate
- f. mg Organic N:mg Organic P:mgVSS = 0.087:0.016:1

9. Pressurized-recycle flotation thickening of waste activated sludge from fruit processing waste yields only about 2 percent D.S. thickened sludge. A separate system treating 30 percent or greater domestic waste along with fruit processing waste yielded a thickened activated sludge of nearly 4 percent D.S.

10. Net Sludge Growth/day = C x Substrate removed/day $-k_t$ x MLVSS
where

$c=0.49 \ \frac{\text{mg VSS formed}}{\text{mg COD removed}}$ for Pear processing waste

$c=0.46 \ \frac{\text{mg VSS formed}}{\text{mg COD removed}}$ for Peach processing waste

$c=0.57 \ \frac{\text{mg VSS formed}}{\text{mg COD removed}}$ for Apple processing waste

$$k_t=0.115 \times 1.14^{(T-20)} \quad \frac{\text{mg VSS destroyed}}{\text{mg MLVSS-day}}$$

=Endogenous respiration rate at T °C

11. Substrate removal rate = f_t x Substrate Concentration

$$f_t=0.017 \times 1.16^{(T-20)} \quad \frac{\text{mg COD removed}}{\text{mg MLVSS-day-mg/l COD}}$$

$$=0.068 \times 1.16^{(T-20)} \quad \frac{\text{mg BOD removed}}{\text{mg MLVSS-day-mg/l BOD}}$$

= Substrate removal rate coefficient

12. Oxygen required/day = a x substrate removed/day + b x k_t x MLVSS

a=0.34 mg O_2 required/mg COD removed
=0.46 mg O_2 required/mg BOD removed
b=1.2 mg O_2 required/mg VSS destroyed by endogenous respiration

13. Cost of treatment is estimated to be:

$0.041/#BOD removed for Aerated Lagoon
$0.061/#BOD removed for Activated Sludge
$0.067/#BOD removed for Contact Stabilization

ACKNOWLEDGMENTS

The studies reported on herein were supported in part by Research and Development Project 12060 FAD of the Federal Water Quality Administration, Department of the Interior. The staff and management of Snokist Growers and Gray and Osborne, Consulting Engineers are acknowledged for their valuable contributions.

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CANNERY WASTE TREATMENT BY TWO-STAGE AERATION PROCESS

by

Leale E. Streebin, George W. Reid, and Alan Hu*

The Stilwell Canning Company, located in Stilwell, Oklahoma, approached the Oklahoma Economic Development Foundation in 1965 to determine if there were government grants available for waste treatment. Being consultants to the foundation, the authors were called upon to assess the problem.

This company employs approximately 450 persons ten months a year, and it is located in an economically depressed area; therefore, to qualify for government assistance, it was only necessary to determine the need. After meeting with the Stilwell city officials and personnel from the canning company, this was not difficult to establish. It was readily apparent that if the canning company was forced into waste treatment without government assistance, it would be forced to close down. It was also apparent that without some improvement in its waste handling procedures, it would not be able to continue to operate.

At that time the waste was divided into two streams. The strong wastes (wastes from Irish and sweet potatoes) were pumped out about three-fourths of a mile over a 500 foot hill to a lagoon and then sprayed on an orchard. This system was not operated properly and, as a result, several problems existed, not the least of which were odors which at times were noticeable more than a mile downwind. To control odors, sodium nitrate was added to the lagoon, which killed some of the fruit trees. At this point the orchard owner issued an order to stop irrigation.

The weaker wastes (wastes from green products) were discharged to the city system which was designed for 6,000 people and was treating the waste from 2,600 people plus the cannery waste with a population equivalent to from 7,200 to 15,000 which completely overwhelmed the treatment plant. The effluent was discharged into Caney Creek, a spring-fed stream with a flow during the critical summer months roughly equivalent to the waste flow. After a flow of sixteen miles, Caney Creek discharges into Lake Tenkiller, a major water recreation

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area. The stream had no trace of D. O. for a reach of more than five miles while the cannery was in operation and as a result there were numerous complaints of odors and in general a bad rapport between the city residents and the cannery even though the cannery hires 450 people in a town of only 2,600.

PROBLEM

The problem was to provide an integrated disposal system for the canning plant capable of treating the highest strength, most unbalanced, and largest volume wastes to a degree compatible with the receiving stream. This was no small task because organic load per shift varies by more than 60 fold, from a volume of 0.389 mgpd and COD of 150 mg/l for spinach wastes to greater than 1.91 mgpd and a strength 5,500 mg/l while processing sweet potatoes. To solve the problem, a research study undertaken which included an initial survey; a detailed analysis of waste orgin, strength and volume; literature review; review of survey data taken by the Oklahoma State Health Department and others; a bench scale model study to verify loadings and nutrient requirements; and finally, recommendations for process selection and scope design.

Based on the information gathered and reported elsewhere, (1) the problem was to develop a process that would most economically reduce an unbalanced waste (C/N/P = 1200/11.6/1) ranging from 0.4 mgd to 2 mgd and from 150 to 5,500 mg/l COD to a level compatible with the receiving stream. Several systems were considered including trickling filters, minimal solids, moderate solids, and extended solids aeration and biosorption systems.

The incoming waste in question has a very high strength; therefore, trickling filters and biosorption systems were deleted from consideration because they were not capable of meeting the required standards without polishing ponds or other tertiary treatment systems. Moderate solids or extended aeration systems, though efficient in terms of percentage removals, would suffer from size diseconomies; therefore, a dual or two stage aeration process was chosen.

The first is a high rate process with high loading capability, followed by a more efficiently polished-effluent-producing process, i.e., minimal solids followed by extended aeration. Minimal solids processes have a short sludge retention time (SRT); a high $\Delta M/\Delta F$ ratio (ΔM = change in active solids and ΔF = change in organic concentration), and a high loading rate (greater than 2.0 lbs COD/Day/lb VSS). With this process the removal rates are extremely high, the removal efficiencies low, and the mixed liquor suspended solids highly dispersed; therefore, the process, though efficient in terms of dollars per pound of COD removal, must be followed with another process.

The process chosen, an extended aeration process, has a loading rate of about 1/100th the rate of a minimal solids system, a $\Delta M/\Delta F$ ratio much lower, and SRT perhaps 100 times greater. The two stage aeration system combines the desirable characteristics of both. The high rates of removal are provided by the minimal solids basin and polished effluent and aerobic sludge digestion by the extended solids aeration basin.

RECOMMENDED PROCESS

The two stage aeration system designed (shown in Figure 1) consists of screens to remove gross solids which are trucked to a previously existing landfill. After screening the waste flows to a minimal solids basin, which was designed to remove 50 percent of the soluble BOD, and then to two low rate extended aeration basins, designed as polishing units. Aeration is followed by final clarification. Provisions are built into the system to return the sludge to the front of all aeration tanks and to maintain a recirculation ratio of approximately one to one. Occasionally it is necessary to withdraw excess sludge from the system which is routed to sludge retention basin for anaerobic digestion.

This system is so designed that it can accomplish a high degree of treatment at the design capacity without a primary clarifier. With the addition of a primary clarifier, which will remove approximately 50 percent of the BOD, and a retention cell for solids disposal, the capacity of the system will be increased by a factor of approximately two.

This plant is so designed that any one of the treatment units may be operated individually or in conjunction with other units. This modular design makes the plant ideal for optimal operation and research. It can be operated as a minimal solids, moderate solids, or extended solids aeration process or a combination of any of these processes. Other parameters that can be controlled are solids retention time, hydraulic retention time, and power input to the surface aerators.

The recommended design criteria is given in Table 1.

DEMONSTRATION GRANT

Benefiting from the grant-in-aid program of the Federal Water Quality Administration of the U. S. Department of Interior and a grant from the Economic Development Administration Office of the U. S. Department of Commerce, the plant was constructed and started operation in May, 1969.

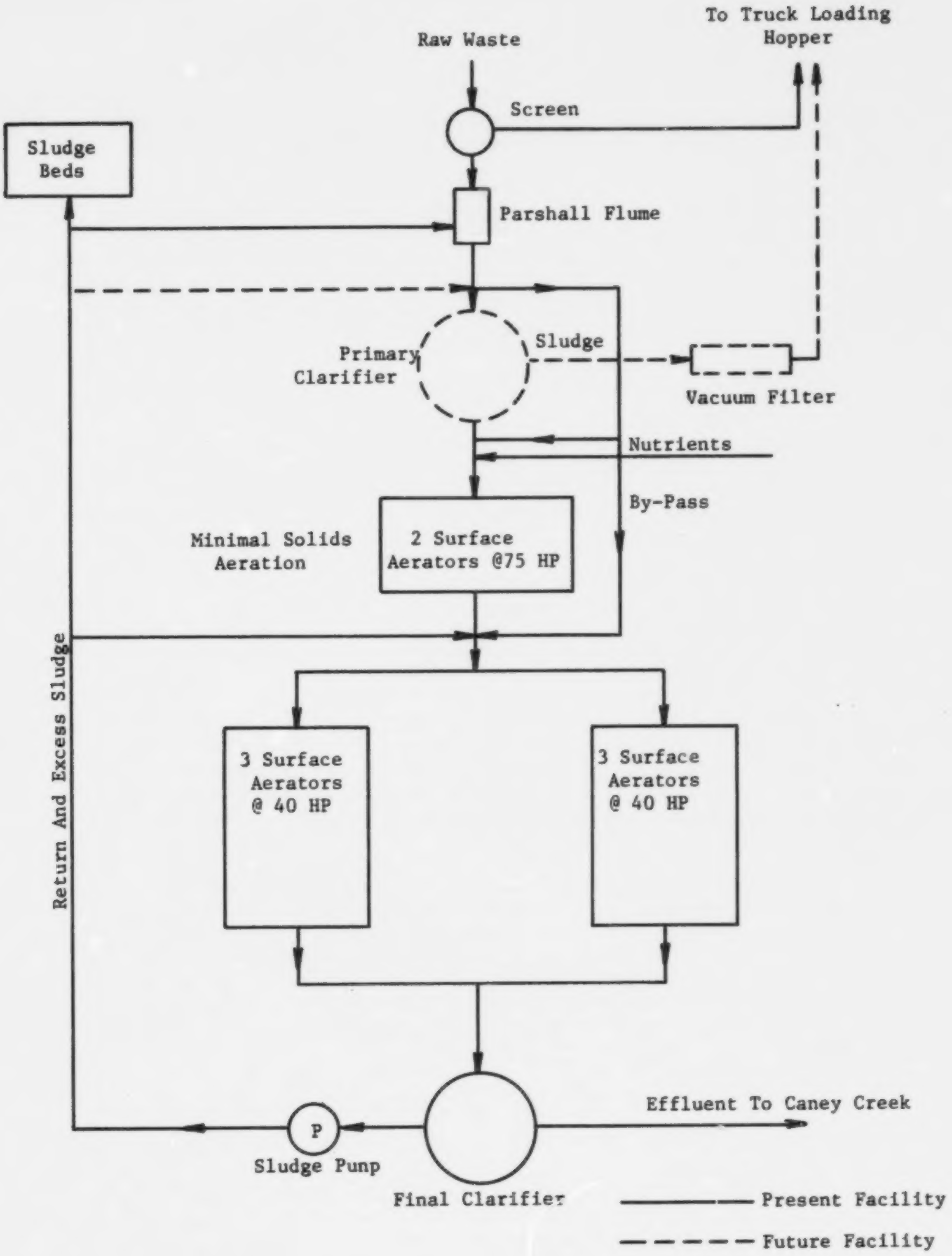

To Truck Loading Hopper
Raw Waste
Screen
Sludge Beds
Parshall Flume
Primary Clarifier
Sludge
Vacuum Filter
Nutrients
By-Pass
Minimal Solids Aeration
2 Surface Aerators @75 HP
Return And Excess Sludge
3 Surface Aerators @ 40 HP
3 Surface Aerators @ 40 HP
Effluent To Caney Creek
P
Sludge Punp
Final Clarifier
Present Facility
Future Facility

Figure 1. FLOW DIAGRAM

Table 1. Design Criteria

1. Design Flow = 1.5 MGD
   BOD = 1,500 mg/l

2. Minimal Solids Unit
   Vol = 40,584 ft^3 = 0.30 MG
   Depth = 8 ft
   Top = 116 ft x 66 ft
   Bottom = 84 ft x 34 ft

   HRT = $\frac{0.3}{1.5}$ = 4.87 hrs

3 Organic loading, COD = 20,000 lbs COD/day

4. HP provided = 2 surface
   aerators @ 75 HP
   total 150 HP

5. Extended Aeration

   HRT = $\frac{2.29 \text{ MG}}{1.5 \text{ MGD}}$ = 36 hrs
   Vol = 2.29 MG
   HP provided = 240 HP

6. Final Clarifier

   Overflow rate based on
   1.5 MGD = 800 gpd/ft^2
   Depth = 8 ft
   Diam. = 50 ft
   DT 1.5 MGD = 1.89 hrs
   Weir loading 1.5 MGD = 10,000 gpf/day

7. Return Sludge Pumps
   2 sets @ 500 gpm
   with TDH = 48 ft
   No sludge flow meter provided

8. Chemical Feeder
   1 set day feeder
   @ 1,000 lbs/day

A demonstration grant was secured from FWQA to study the system and to show that a high strength, large volume, nutritionally unbalanced, cannery waste can be successfully treated to a high degree by the two stage aeration process. The results will be used in establishing design criteria for the treatment of fruit and vegetable waste treatment using a two stage aeration process.

The scope of this research includes:

1. Collection and analyses of the various vegetable and fruit wastes as they are produced and discharged from the cannery.

2. Determination of waste flows for each product processed.

3. Studies on the waste characteristics and the removal efficiencies for each modular process and the entire system.

4. Evaluation of receiving water response to discharged wastes.

The Stilwell Canning Company cans and freezes a wide variety of vegetables and fruits which include spinach, strawberries, greens, beans, yellow squash, okra, peas, white potatoes, and sweet potatoes with potatoes being the dominant product. A production schedule is shown in Table 2.

Within this variety of products being processed during the canning season, it is evident that the organic strength and flow fluctuates widely. Seasonal changes and moreover changes between and within shifts are reflected in the waste stream makeup. In order to cope with changing production, the activities within the cannery were followed closely and recorded at the time of sampling.

SAMPLING

Because the primary purpose of this project was to study treatment efficiency and cannery waste characteristics, the sampling program had to be developed to monitor the changes in waste flow and strength and to establish the effects of these changes on treatment efficiencies.

In any sampling program, considerable thought must be given to the location of sampling points. Sampling points should conform to hydraulic suitability, that is, points of high turbulence that assure good mixing should be selected. The points must also be located so that individual process unit efficiencies could be determined. Examination of the plant layout indicated that sampling from

Table 2. Production Record

Processing Time	Year	Production Cases	Water Used MGD	Peak Month	Peak Production Cases
Apr - Dec	1965	1,494,266	1.5	Oct	234,311
Apr - Dec	1966	1,650,000	0.84	Sept	268,000
Apr - Dec	1967	1,750,000			
Apr - Dec	1968	1,800,000			
May - Nov	1969	1,979,000		Sept Oct	294,741 271,294

Case = 24 @ 303 can

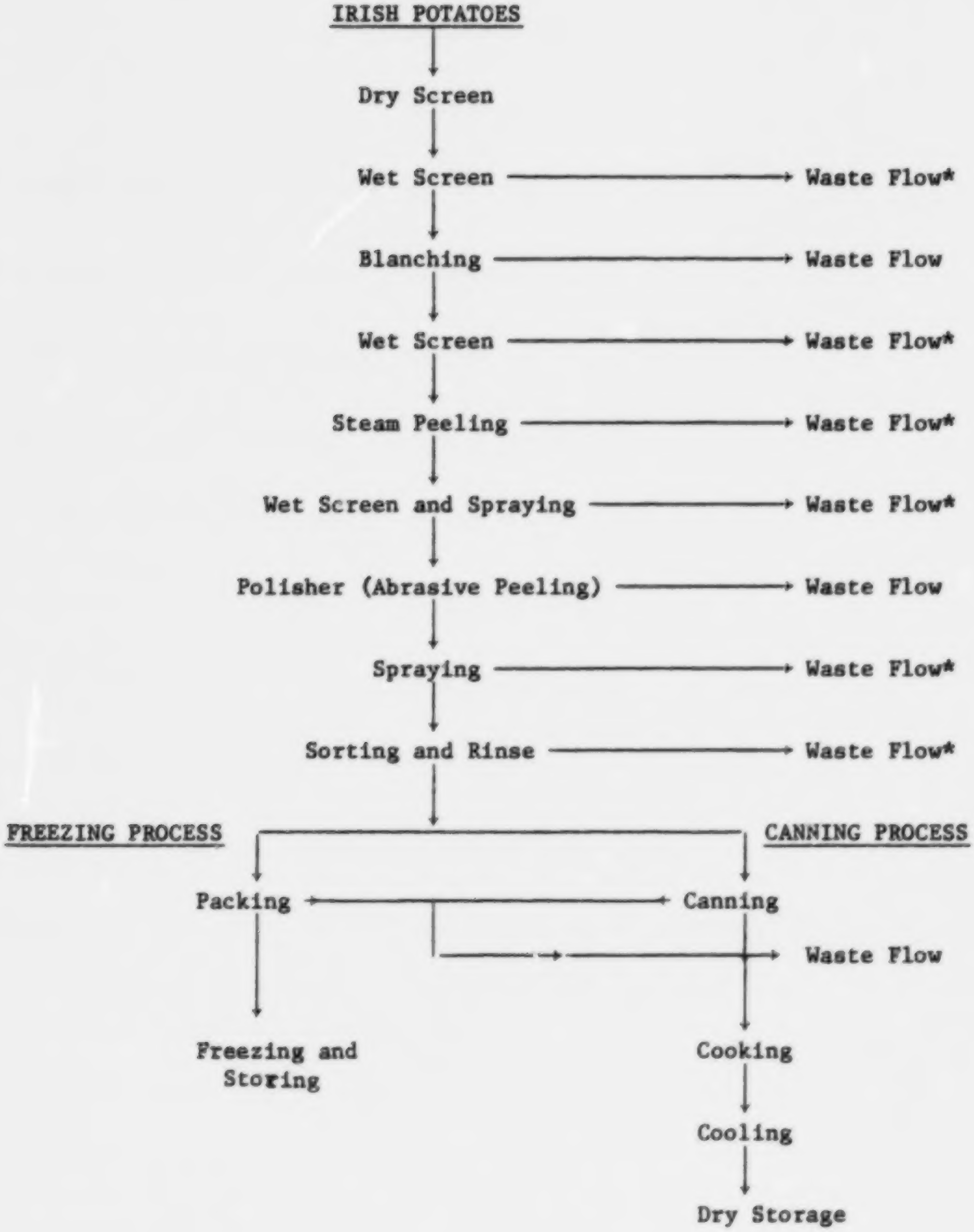
1969 Production Schedule

Month	Products
May	Spinach, Mustard Green, Collard Green, Turnip Green, Strawberry, Irish Potato
June	Green Beans, Irish Potato, Squash, Peas, Blackberry
July	Green Beans, Okra, Squash, Irish Potato, Peas
August	Irish Potato, Okra, Peas, Sweet Potato
September	Sweet Potato, Irish Potato, Okra, Peas, Butter Beans, Squash, Green Beans
October	Sweet Potato, Irish Potato, Okra, Squash, Butter Beans, Lima Beans, Peas, Turnip Green, Mustard Green
November	Sweet Potato, Collard Green, Turnip Green, Spinach

the Parshall Flume, the minimal solids aeration unit, the extended solids aeration unit, and after the final clarifier would yield homogeneous samples that could be used to determine waste characteristics and plant efficiencies.

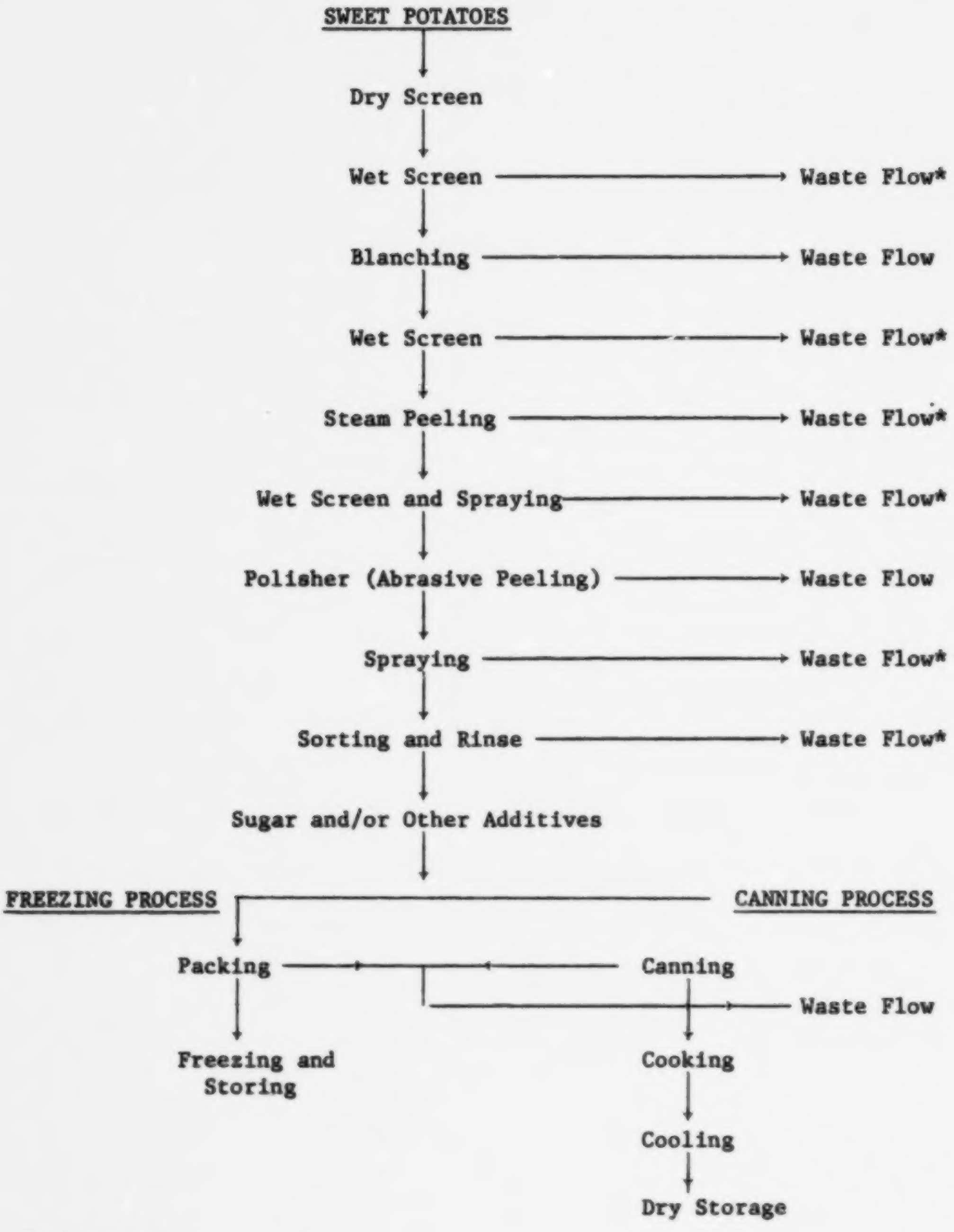
Sampling and flow determinations were also considered within the cannery but were not run because the various waste streams within a process were integrated with streams from other simultaneously operating processes. Referring to the flow diagrams in Figures 2 through 10, notice that there is a minimum of four waste streams (excluding blackberry) per product processed. Therefore, a complete analysis and flow determination of waste streams from each product processed was not practical because it would have necessitated the complete analysis of a minimum of twelve streams plus the analysis of the waste treatment system. A complete analysis of the treatment system included the following:

1. Raw waste	Total and soluble COD Total, Settleable, Suspended and Volatile Solids
2. After screening	Total and soluble COD Total, Settleable, Suspended and Volatile Solids Kjeldahl, Nitrite, Nitrate, and Ammonia Nitrogen Total Phosphate Alkalinity, pH, temp. Chlorides
3. Minimal Solids	Total and soluble COD MLSS and MLVSS Dissolved Oxygen Kjeldahl, Nitrite, Nitrate, and Ammonia Nitrogen pH, temp
4. Extended Aeration and Final Clarifier	Total and soluble COD in effluent MLSS and MLVSS Dissolved Oxygen Kjeldahl, Nitrite, Nitrate, and Ammonia Nitrogen in tank and in effluent Settling Study Total phosphate in tank and in effluent Effluent Suspended and Volatile solids pH, temp.
5. Sludge	% Volatile Material and Sludge Concentration


IRISH POTATOES
Dry Screen
Wet Screen
Waste Flow*
Blanching
Waste Flow
Wet Screen
Waste Flow*
Steam Peeling
Waste Flow*
Wet Screen and Spraying
Waste Flow*
Polisher (Abrasive Peeling)
Waste Flow
Spraying
Waste Flow*
Sorting and Rinse
Waste Flow*
FREEZING PROCESS
CANNING PROCESS
Packing
Canning
Waste Flow
Freezing and Storing
Cooking
Cooling
Dry Storage

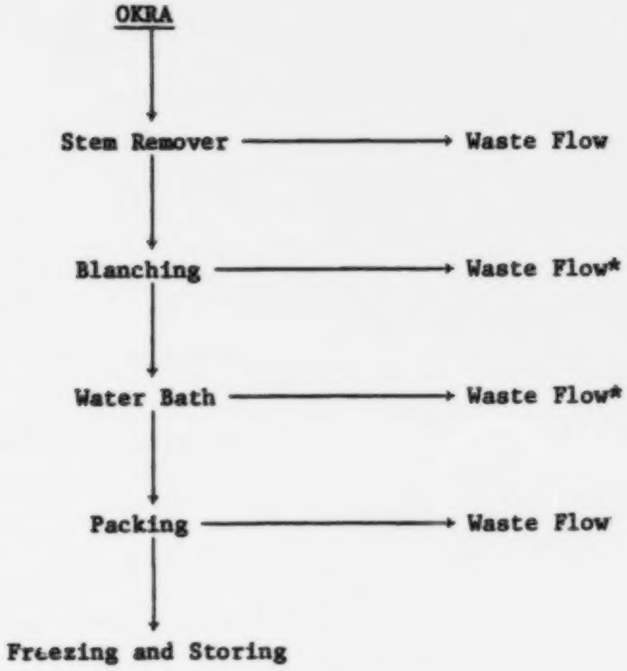
* Major Stream

Figure 2. FLOW SHEET OF IRISH POTATO PROCESSING


SWEET POTATOES
Dry Screen
Wet Screen
Waste Flow*
Blanching
Waste Flow
Wet Screen
Waste Flow*
Steam Peeling
Waste Flow*
Wet Screen and Spraying
Waste Flow*
Polisher (Abrasive Peeling)
Waste Flow
Spraying
Waste Flow*
Sorting and Rinse
Waste Flow*
Sugar and/or Other Additives
FREEZING PROCESS
CANNING PROCESS
Packing
Canning
Waste Flow
Freezing and Storing
Cooking
Cooling
Dry Storage

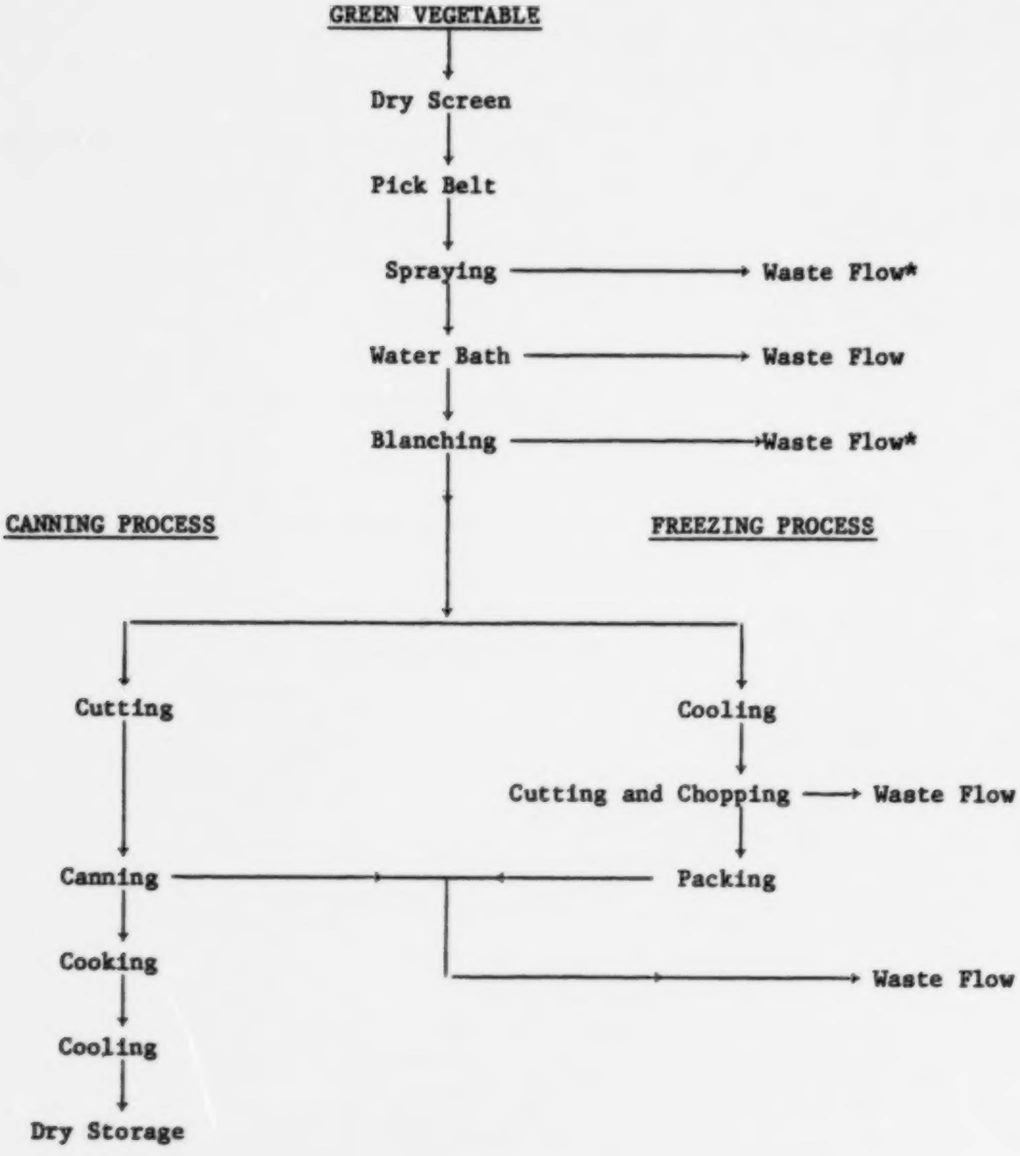
*Major Stream

Figure 3. FLOW SHEET OF SWEET POTATO PROCESSING


OKRA
Stem Remover
Waste Flow
Blanching
Waste Flow*
Water Bath
Waste Flow*
Packing
Waste Flow
Freezing and Storing

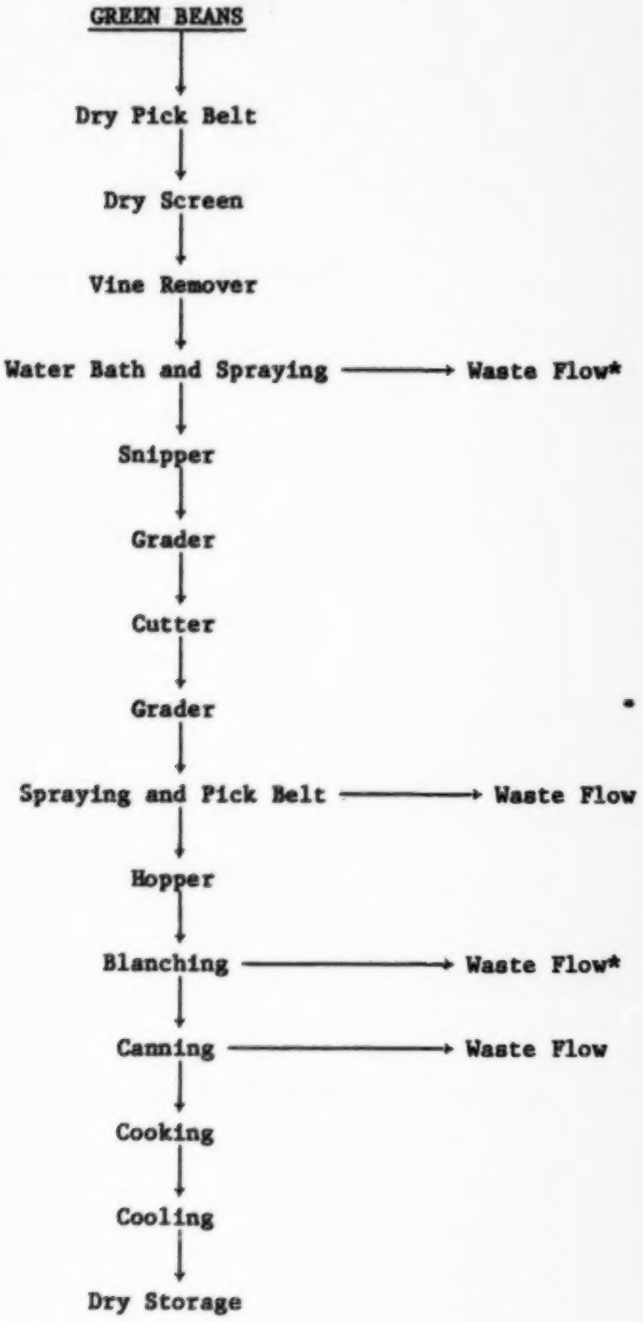
*Major Stream

Figure 4. FLOW SHEET OF OKRA PROCESSING


GREEN VEGETABLE
Dry Screen
Pick Belt
Spraying
Waste Flow*
Water Bath
Waste Flow
Blanching
Waste Flow*
CANNING PROCESS
FREEZING PROCESS
Cutting
Cooling
Cutting and Chopping
Waste Flow
Canning
Packing
Waste Flow
Cooking
Cooling
Dry Storage

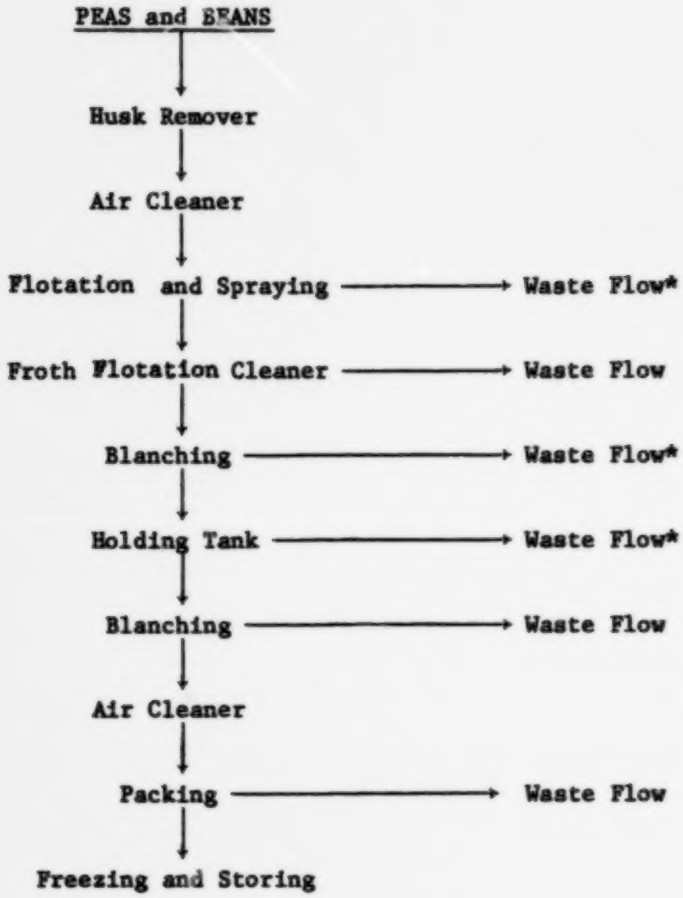
*Major Stream

Figure 5. FLOW SHEET OF GREEN VEGETABLE PROCESSING


GREEN BEANS
Dry Pick Belt
Dry Screen
Vine Remover
Water Bath and Spraying
Waste Flow*
Snipper
Grader
Cutter
Grader
Spraying and Pick Belt
Waste Flow
Hopper
Blanching
Waste Flow*
Canning
Waste Flow
Cooking
Cooling
Dry Storage

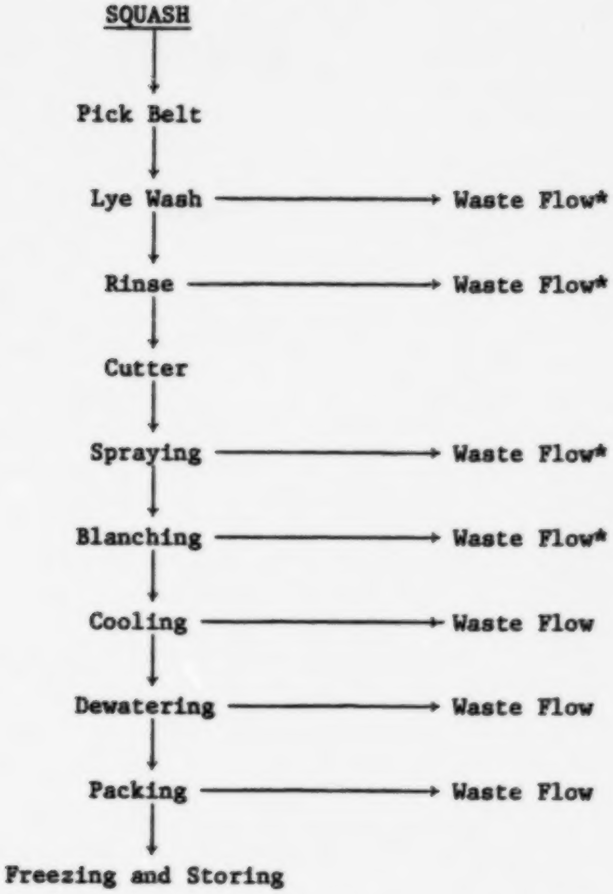
*Major Stream

Figure 6. FLOW SHEET OF GREEN BEAN PROCESSING


PEAS and BEANS
Husk Remover
Air Cleaner
Flotation and Spraying
Waste Flow*
Froth Flotation Cleaner
Waste Flow
Blanching
Waste Flow*
Holding Tank
Waste Flow*
Blanching
Waste Flow
Air Cleaner
Packing
Waste Flow
Freezing and Storing

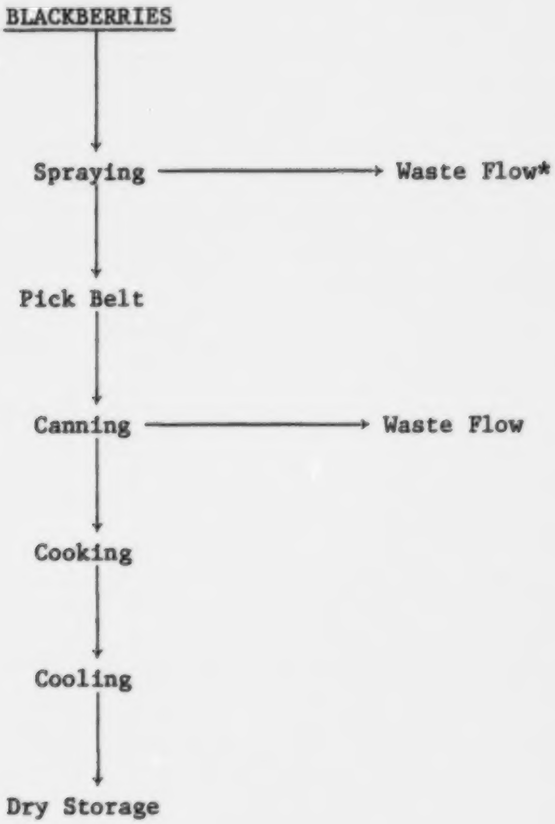
*Major Stream

Figure 7. FLOW SHEET OF PEAS AND BEANS PROCESSING


SQUASH
Pick Belt
Lye Wash
Waste Flow*
Rinse
Waste Flow*
Cutter
Spraying
Waste Flow*
Blanching
Waste Flow*
Cooling
Waste Flow
Dewatering
Waste Flow
Packing
Waste Flow
Freezing and Storing

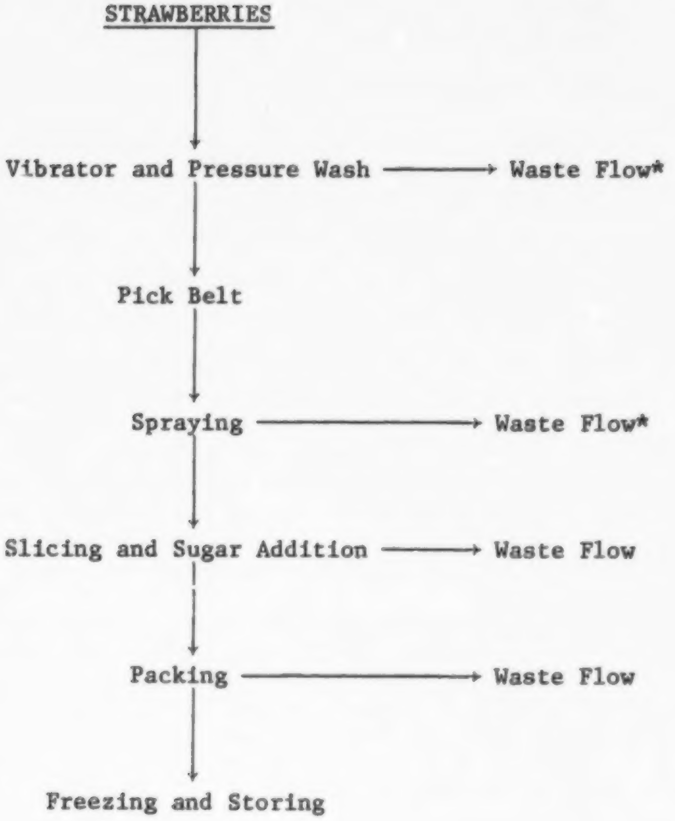
* Major Stream

Figure 8. FLOW SHEET OF SQUASH PROCESSING


BLACKBERRIES
Spraying
Waste Flow*
Pick Belt
Canning
Waste Flow
Cooking
Cooling
Dry Storage

*Major Stream

Figure 9. FLOW SHEET OF BLACKBERRY PROCESSING


STRAWBERRIES
Vibrator and Pressure Wash
Waste Flow*
Pick Belt
Spraying
Waste Flow*
Slicing and Sugar Addition
Waste Flow
Packing
Waste Flow
Freezing and Storing

*Major Stream

Figure 10. FLOW SHEET OF STRAWBERRY PROCESSING

Equal in importance to collection of a good sample is the preservation of this sample between the time of sampling and analysis. Waste water samples are unstable due to their chemical, physical, and biological characteristics. Since all analyses were conducted in a mobile laboratory at the treatment plant, refrigeration was used for preservation.

FLOW DETERMINATION

Estimates of flow volumes in cannery operation are needed for design and planning purposes. It was desired to use the data taken in the study of the cannery to develop and verify a prediction scheme which then might be used to predict flows at the Stilwell site or used for prediction for design purposes at other locations. The best means was believed to be estimating the flow per case for each vegetable type in the cannery by use of a predictive equation.

The data available for this study was a continuous flow record at the entry to the waste treatment plant and production figures for each shift (night and day) by vegetable type in cases of #303 cans.

The flow measured at the treatment plant was a combination not only of all waste streams but of infiltration into approximately 1.5 miles of line between the cannery, the treatment plant, and domestic sewage for about eighteen families.

The periods of production usually included several vegetable types during a shift. Not enough periods of processing of single vegetable types could be obtained during the six months of study to examine even the most commonly occurring vegetable types separately. Therefore, the indicated approach was decomposition of the flow into portions associated with each of the vegetables. The approach chosen was the linear model listed below with multiple regression estimates of the parameters:

$$F = b + aI + b_1P_1 + b_2P_2 + \dots\dots\dots\dots\dots\dots \; b_iP_i$$

F is flow volume in gallons during the period for which production is reported; b is a constant flow associated with the plant being in operation for the period and represents internal waste water, cooling water, cleanup water, etc., which cannot be associated with individual processes, etc; a is a coefficient; I is the infiltration and domestic sewage input below the cannery; P_i is the production in cases for the ith vegetable type, and b_i is the fpc for the ith vegetable type. I was estimated by base flow during non-production periods.

Initial analysis was done on the basis of separate shifts. The shift values were generally reasonable although the estimated fpc for squash was negative for both shifts and for okra in the night shift. The break between shifts was based on information provided by the company which was used for payroll data.

Observing the processes indicated that the time of division between shifts was not always reliable, because the actual processing might proceed or follow the nominal shift by several hours and cause significant error in the flow breakdown between shifts. To avoid this source of error, the shifts were combined and each day run as an individual data value. The estimates of fpc were all positive, the estimate of the constant b was smaller for the work day than for either shift, and the multiple correlation coefficient was higher than that for either of the individual shifts. The results of this run are shown in Table 3.

The coefficient "a" would normally be 1.0 but was allowed to be fitted because it was desired to see if the estimates of infiltration by using periods of no production were reliable. Values for the coefficient much less than or greater than 1.0 would indicate unreliability. In the studies made to date, the coefficient has ranged from 1.0 to 1.6 and in future studies will be assumed 1.0 and not estimated.

The error analysis for this run is shown in Table 4. The sources of error in estimating this relationship are:

1. Error in flow measurement
2. Error in reporting production
3. Variability in fpc
4. Variability in nonprocess water (constant term)

The first source is normally about 5%-10% based on the listed performance for the flow measuring device. However, several days during the study period, the capacity of the flow measuring device was exceeded and the flow measured manually. What the error was in these cases is unknown.

The second source is uncertain in quantity. The production figures should be exact; however, it is possible some processing was partly completed and the vegetables stored and finished and reported the next day.

The third and fourth sources of error are errors which are due to estimating averages for values which actually show a distribution. There is certain to be some variation in fpc because of the differences in raw product quality for a vegetable type, possibly seasonal variation, variation due to operating personnel and that due

Table 3. Estimates of Parameters

			t Value*
Constant b			
Infiltration coefficient a		1.30	4.71
Vegetable	FPC	(gals)	
Irish Potatoes		153	12.17
Okra		6	51.00
Peas		26	2.81
Sweet Potatoes		147	13.15
Beans		72	3.06
Squash		5	.39
Green Beans		41	8.17
Mustard Greens		109	5.97
Turnip Greens		69	7.54
Collard Greens		35	1.71
Spinach		61	7.98

*t = 1.29 @ 10%, t = 1.66 @ 5%, t = 2.36 @ 1% levels of significance

Table 4. Error Analysis

Multiple Correlation Coefficient	.906
Standard Error of Estimate	148,600 gals
Average Flow per Workday	696,900 gals
Prediction Error for 147 days (error is residual/observed value)	
percent less than 10%	55.1
percent less than 20%	84.4
percent less than 50%	95.2
average percent error	14.8

to a change in quantity of product processed per unit of time. The amount of water flowing during a shift which is not process water will vary also.

This model may be improved. Variation in flow may be estimated by taking periods of seven, fourteen, or more consecutive days and estimating the parameters for the different periods and seeing what change there is from one period to the next. These results will be included in the final report.

The estimates of fpc for the eleven vegetable types are reasonable in magnitude and are in general agreement with published figures. Since the constant term is only about 10% of the average flow, the estimates of fpc account for most of the water used in processing. Thus, the values of fpc are fair estimates of the average amount of water associated with each case of a particular vegetable processed in this cannery.

The model can be used to predict flows at this site or used at another site by estimating the number of cases processed. The constant term can be estimated as a percentage of the average predicted flow based on assumed production and estimated fpc. The infiltration term would be estimated if there are flow sources outside the plant which need to be added (as for the cannery at Stilwell).

DETERMINATION OF STRENGTH

To better predict and design waste treatment processes, it is desired to predict quantities of pollution based on the production figures as was done in the volume studies. The technique will be used to predict mass rate of flow of the pollutant under consideration during the time interval set for the study (i.e., shift or day). The mass of pollutant produced during the time interval (the mass rate of flow times the interval) will be related to production during the same interval using a model similar to the flow volume model. The estimated flow and mass of pollutant will then be used to determine loading rates for the treatment system.

Flow and production data available are the same as listed above under flow determination. Additional data are chemical analyses performed one to four times daily on samples taken at the flow measuring point.

The prediction of mass rather than concentration is based on the belief that the variation in mass rate of flow of pollutant is less variable than concentration since a constant mass flow would show variation due to dilution.

RESULTS

The two stage aeration system designed to treat 1.5 million gallons at a strength (COD) of 2250 mg/l (BOD_5 = 1,500 mg/l) performed above expectations. The system was designed for what was expected to be ultimate capacity; however, due to unforseen circumstances by the time the treatment plant was constructed, it was already operating above design capacity.

During the six-month study, the flow reached one instantaneous peak of 2.4 mgd and a peak daily flow of 1.9 mgd. The waste strength while processing sweet potatoes peaked 5,500 mg/l. Even at these higher loading rates the soluble COD removal efficiencies for the system exceeded 95 percent. The removal efficiencies based on settled samples were also above 95 percent except during the period of sludge bulking when it dropped to as low as 66 percent. Sludge bulking was due to nutrient deficiencies. Nitrogen was not added to the system while processing the unbalanced sweet potato waste until bulking occurred.

The waste strength and flow varied tremendously as can be seen in Figures 11 through 13. With this radical variation the system had to be capable of receiving shock loads without being adversely affected. Figures 11 and 12 and Table 5 demonstrate the stability of the two stage aeration system. The soluble COD in the plant effluent, except for one period during October when the system was nutrient deficient, was always less than 140 mg/l. The minimal solids system removed from 66 percent to 99 percent of the soluble COD while the loading rate varied from slightly less than 1 lb COD/lb MLVSS to greater than 20 as shown in Figure 14. This is somewhat misleading because a high percentage (up to 60 percent) was converted to cellular material which resulted in a load on the extended aeration system.

The analyses are not complete on the extended aeration units; however, the soluble COD removal efficiencies exceeded 94 percent except during periods of upset due to nutrient deficiencies. The volatile solids removal efficiencies was generally greater than 90 percent. Further results will be reported in the final report.

The waste treatment system protected the receiving stream. The stream, with a flow during the summer months approximately equivalent to the waste flow, maintained a D.O. concentration greater than 4.0 mg/l for its entire length during the entire canning season. However, during the period of sludge bulking the stream did suffer some damage due to sludge deposits.

CONCLUSIONS

1. The two stage aeration system is very stable and capable of accepting shock loads without being adversely affected.

2. The system is flexible. The various units can be operated separately to match the flow and strength variation.

3. The minimal solids can be started up readily by recycling the mixed liquor from the extended aeration system.

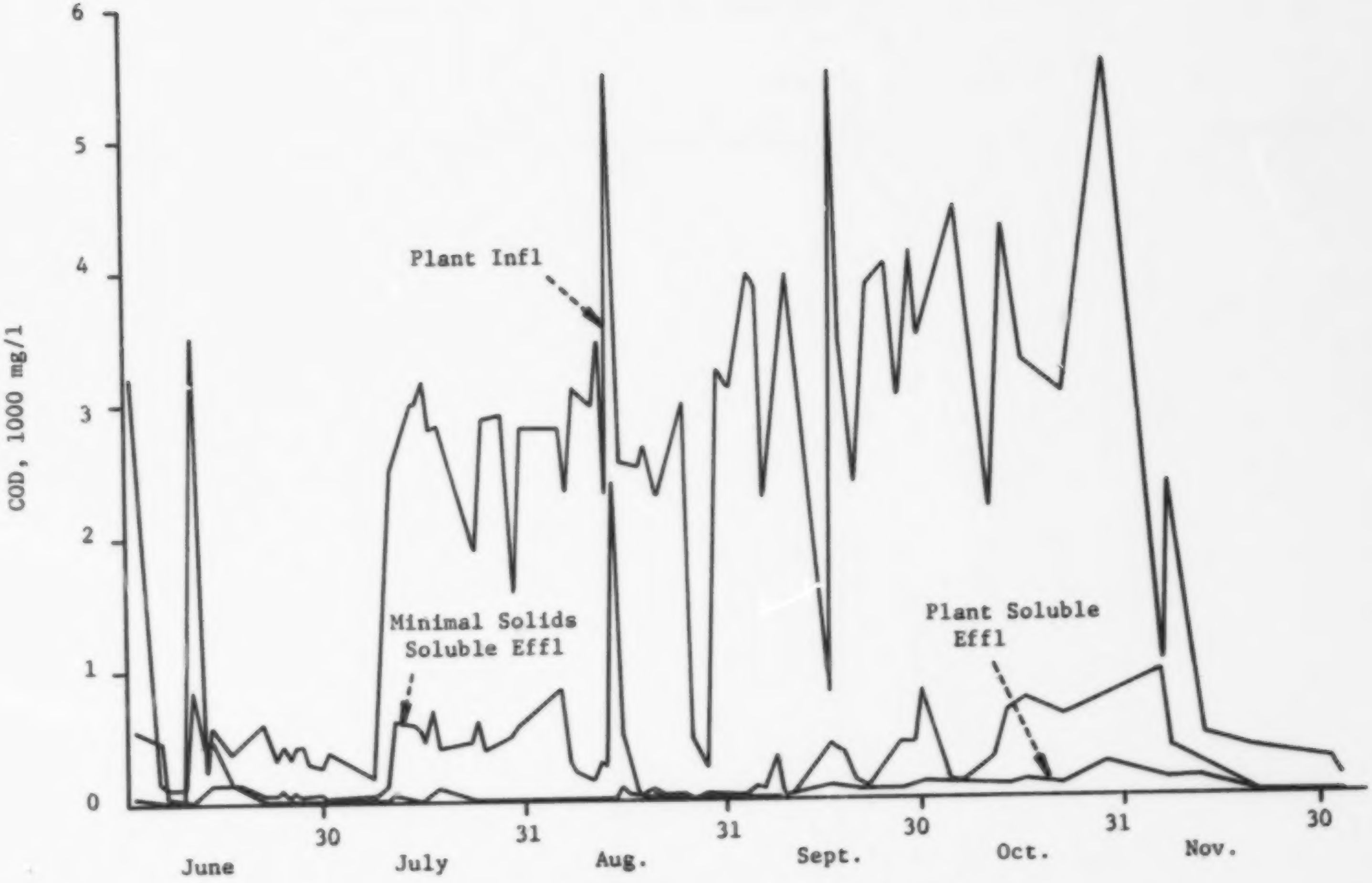


Figure 11. TREATMENT PLANT OPERATION DATA

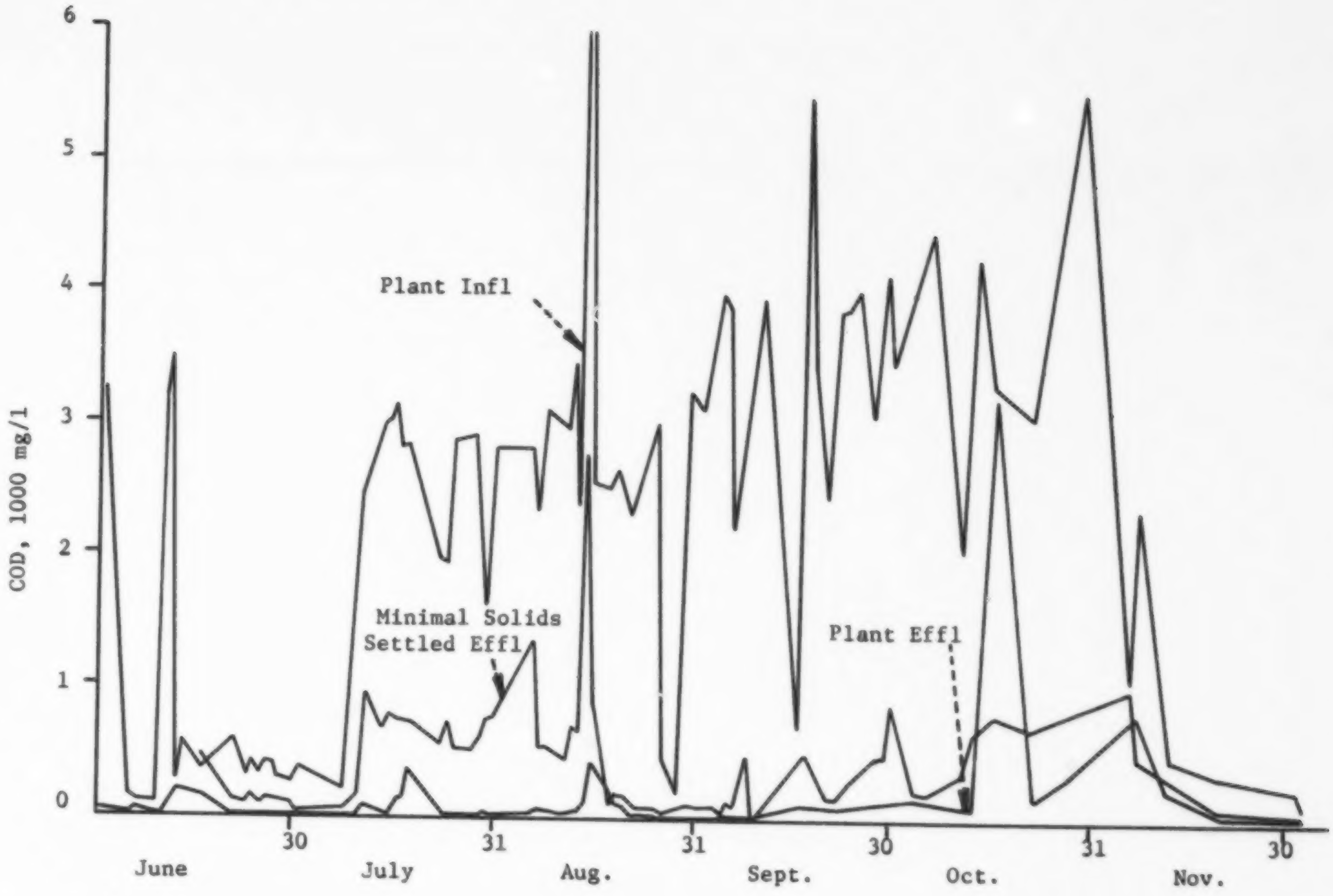


Figure 12. TREATMENT PLANT OPERATION DATA

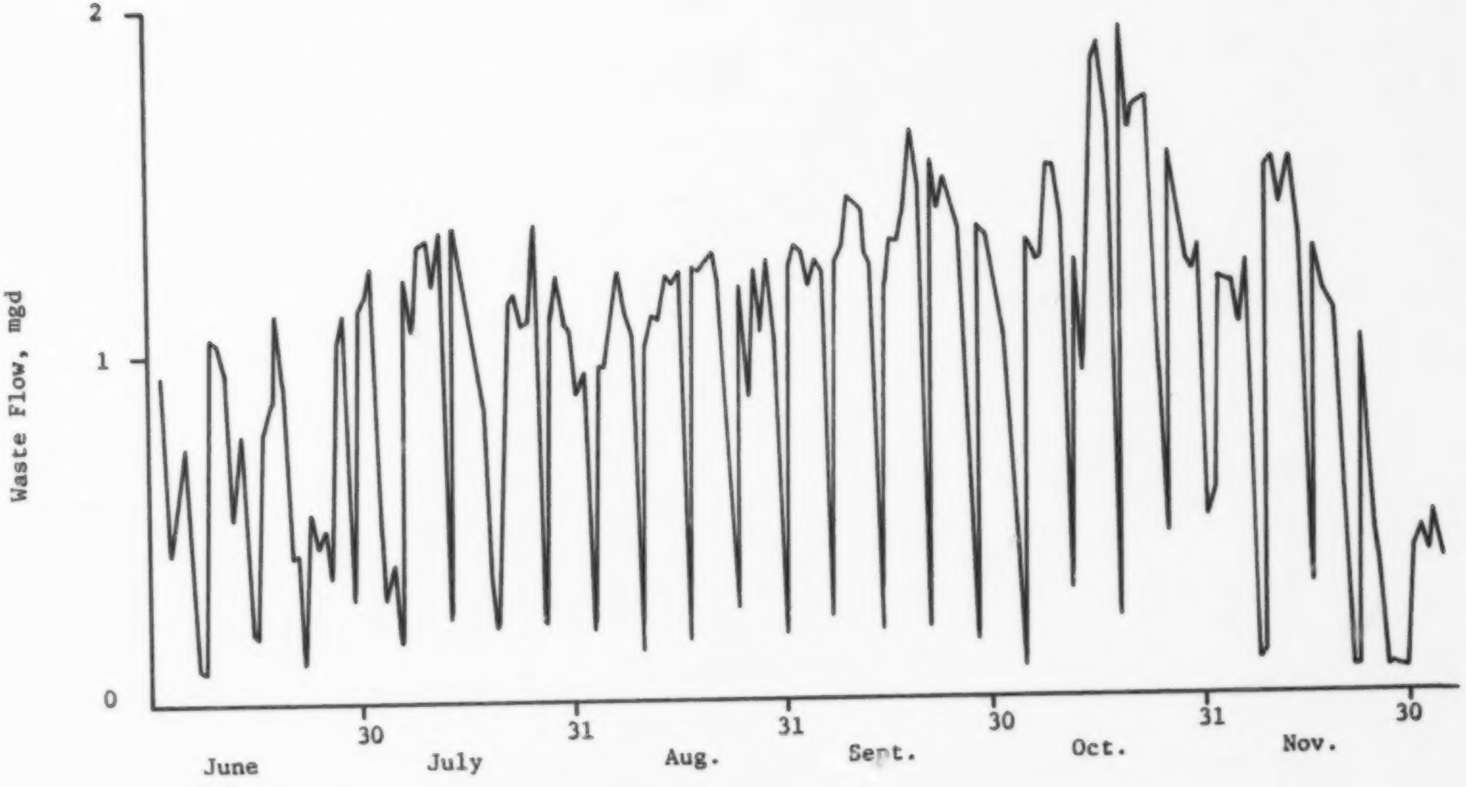


Figure 13. FLOW VARIATION

Table 5. Plant Performance Data

A. Products Processed:

Sweet potato, okra, peas, squash, beans, turnip green, and cobbler. (The daily process included sweet potato and one or more of the other products.)

1. Plant Influent Characteristics

	Solids				COD					
	SS	DS	VSS	VDS	Total	Settled	Soluble	pH	T°C	TKN
Min.	1150	1300	860	1110	3060	1700	1190	5.3	23	14
Max.	2540	3120	2400	2850	5500	3380	3240	7.9	33	59

2. Performance in Minimal Solids Unit

	MLSS	MLVSS	lbs COD / lbs MLVSS/day	Δlbs COD / lbs MLVSS/day		COD Removal, %		SVI
				settled	soluble	settled	soluble	
Min.	2500	2000	4.00	4.00	4.05	74	76	150
Max.	4200	3600	9.26	7.51	7.75	99	99	270

3. Performance of Extended Aeration Unit, including Final Clarifier

	SS	VSS	COD Removal %		Effluent COD		Solids Removal %		SVI	pH
			Total	Soluble	Total	Soluble	SS	VSS		
Min.	8	5	66	94	19	Trace	87	94	140	6.8
Max.	180	83	99	99	186	128	99	99	300	7.6
	2915*	2390*			3190*	268				

*Bulking Sludge, solids unloaded

Table 5. (Cont'd.) B. Products Processed

Irish potato, okra, peas, beans, green beans

1. Plant Influent Characteristics

	Solids					COD				
	SS	DS	VSS	VDS	Total	Settled	Soluble	pH	T°C	TKN
Min.	840	876	810	667	2016	1000	911	4.6	29	
Max.	2036	1728	1924	1360	4229	1550	1390	7.2	37	77

2. Performance in Minimal Solids Unit

	MLSS	MLVSS	lbs COD / lbs MLVSS/day	Δlbs COD / lbs MLVSS/day Settled	Δlbs COD / lbs MLVSS/day Soluble	COD Removal % Settled	COD Removal % Soluble	SVI
Min.	840	700	2.56	2.42	2.44	63	77	50
Max.	4270	3521	10.96	8.65	9.98	98	99	256

3. Performance of Extended Aeration Unit, including Final Clarifier

			COD Removal %		Effluent COD		Solids Removal %			
	SS	VSS	Total	Soluble	Total	Soluble	SS	VSS	SVI	pH
Min.	8	2	86	95.6	30	10	84.5	85	80	6.80
Max.	212	210	99	99.0	400	120	99.0	99	240	7.65

Table 5.(Cont'd.) C. Products Processed

Green Beans, Squash, and Green Vegetables

1. Plant Influent Characteristics

	Solids				COD					
	SS	DS	VSS	VDS	Total	Settled	Soluble	pH	T°C	TKN
Min.	18	221	15	116	112	82	82	6.1	22	14
Max.	378	664	220	415	495	495	445	10.2	31	24

2. Performance in Minimal Solids Unit

	MLSS	MLVSS	lbs COD / lbs MLVSS/day	Δlbs COD / lbs MLVSS/day Settled	Δlbs COD / lbs MLVSS/day Soluble	COD Removal % Settled	COD Removal % Soluble	SVI
Min.	123	63	2.39	1.05	2.39	33	66	43
Max.	1690	880	14.16	12.23	13.84	86	98	200

3. Performance of Extended Aeration Unit, including Final Clarifier

	Solids		COD Removal %		Effluent COD		Solids Removal %			
	SS	VSS	Total	Soluble	Total	Soluble	SS	VSS	SVI	pH
Min.	3	Trace	56	64	5	Trace	69	74	46	7.1
Max.	60	50	99	99	167	134	99	99	170	8.0

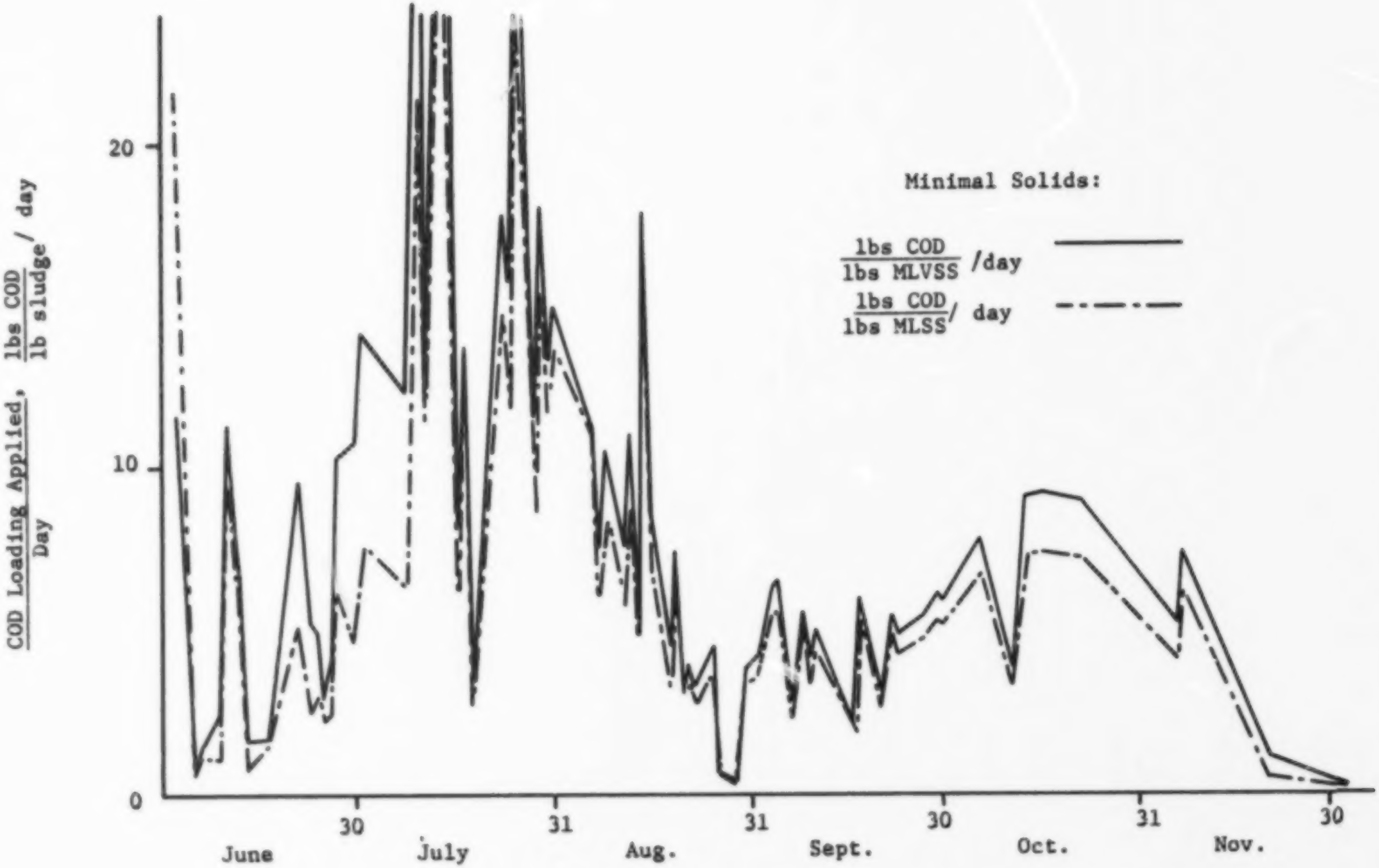


Figure 14. MINIMAL SOLIDS LOADING RATE

4. The loss of sludge during the processing of sweet potatoes was a result of a nitrogen deficiency.

5. The size of the clarifier should be increased and the overflow rates decreased from those recommended for domestic waste treatment systems.

6. The receiving stream maintained a D. O. of above 4 mg/l for the entire stream reach for the entire canning season.

7. The two stage aeration system provides high rates of removal and high treatment efficiencies.

ACKNOWLEDGMENTS

This investigation was supported by Demonstration Grant No. 12060DSB from the Federal Water Quality Administration, for which, we express our sincere appreciation.

The cooperation of the personnel at the Stilwell Department of Utilities, and that of Stilwell Canning Company is gratefully acknowledged.

Thanks are extended to Mr. John Palafox who helped in performing numerous laboratory analyses.

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LIME TREATMENT AND IN-PLANT REUSE OF AN ACTIVATED SLUDGE PLANT EFFLUENT IN THE CITRUS PROCESSING INDUSTRY

by

Richard H. Jones*

The citrus industry of Florida is a $2 billion business which produces 75 percent of the oranges and 80 percent of the grapefruit grown in the United States. Some 50 percent of the grapefruit and 80 percent of the oranges are processed for sale as products other than whole fresh fruit, for example, as frozen concentrates. A recent survey found there were 52 citrus processing plants in the state which discharge 150 mgd of wastewater having an organic loading of 400,000 pounds BOD per day. This is equivalent to the wastewater from 2 million people.

The Winter Garden Citrus Products Co-operative was cited by the Department of Air and Water Pollution Control for discharging their wastewater into Lake Apopka untreated for over 20 years. They were given six weeks in which to find an acceptable method for treating their waste or they would not be allowed to continue operation. Environmental Engineering, Inc., was retained as their consulting engineers and was presented with the task of developing, in a six-week period, an acceptable waste treatment method including control of effluent nutrients. Environmental Engineering, Inc., was also presented the task of obtaining a research, development, and demonstration grant from the FWQA.

DISCUSSION

In the past, the only partially successful method of citrus waste treatment was by land irrigation. This method required large areas of specially suited land, which was seldom available. The Winter Garden Citrus Products processing plant, located in the city of Winter Garden, was therefore limited in the amount of land available for waste treatment.

In Leesburg, Florida, a waste treatment plant had been in operation for two years, combining the city sewage with the concentrated waste from the Minute Maid citrus processing plant for treatment. It was not feasible to combine domestic sewage with the waste from the processing plant in Winter Garden because the city wanted nothing to do with the citrus waste in their existing sewage treatment plant.

A waste treatment plant was under construction in Auburndale, Florida, designed to treat the total flow from two citrus processing plants. This meant treating not only the concentrated wastewater but also the barometric leg and cooling water. If this method had been attempted at Winter Garden, it would have meant treating some 10 mgd of waste with a BOD concentration of 400 mg/l instead of treating just the concentrated waste of 2 mgd with a BOD of 2000 mg/l. Again, there was not enough land available; therefore, this type of treatment process could not be used.

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Neither the citrus waste treatment plant in Leesburg nor Auburndale has operated successfully to date. The main problem with the plant at Leesburg is overloading and lack of facilities to handle waste activated sludge. At the Auburndale plant, the secondary clarifiers have never functioned.

The decision was made to test on a laboratory basis the treatment of concentrated citrus waste alone by the complete mixed activated sludge process. A continuous flow, bench-scale unit was operated for approximately four weeks. Results from this research showed that concentrated citrus waste could be effectively treated in this manner. Further laboratory tests showed that lime treatment of the biologically treated effluent would give a final effluent low in suspended solids and phosphorus.

Based upon this short period of testing, a full-scale plant was designed. Figure 1 shows a schematic of the Winter Garden waste treatment plant as initially constructed. Plant design was based on a flow of 2 mgd and a BOD of 2000 mg/l. Nutrients were added in the form of phosphoric acid and anhydrous ammonia. The pH was controlled with NaOH as required. Concentrated citrus wastewater was pumped into two concrete aeration basins 144 feet in diameter. Side water depth was approximately 12 feet and aeration was provided by three 75 hp floating aerators. The aeration basins were designed so that operation in series or parallel was possible.

Effluent from the aeration basins flowed to a clarifier from which return sludge was pumped back into the influent pipe to the aeration basins. Effluent from the clarifier flowed to the lime treatment tank, then either back to the citrus plant for reuse or directly to Lake Apopka. Waste sludge from the clarifier and lime treatment tank were discharged to a wet well, then pumped to a surge tank back in the citrus plant. The surge tank also served as a sludge thickening tank. Thickened sludge from the bottom of the surge tank was pumped through a solid bowl centrifuge. The supernatant was returned to the plant influent, and the solids cake was mixed with pressed citrus peel for recovery as cattle feed.

The FWQA awarded a research and development grant to Winter Garden Citrus covering only the lime treatment unit, as a previous grant had been awarded on activated sludge treatment of citrus waste at Leesburg and Auburndale, Florida. However, Winter Garden Citrus Products Co-op. was requested to provide complete chemical analyses on the activated sludge portion of the treatment process and include the data in all reports. The grant plan had several objectives:

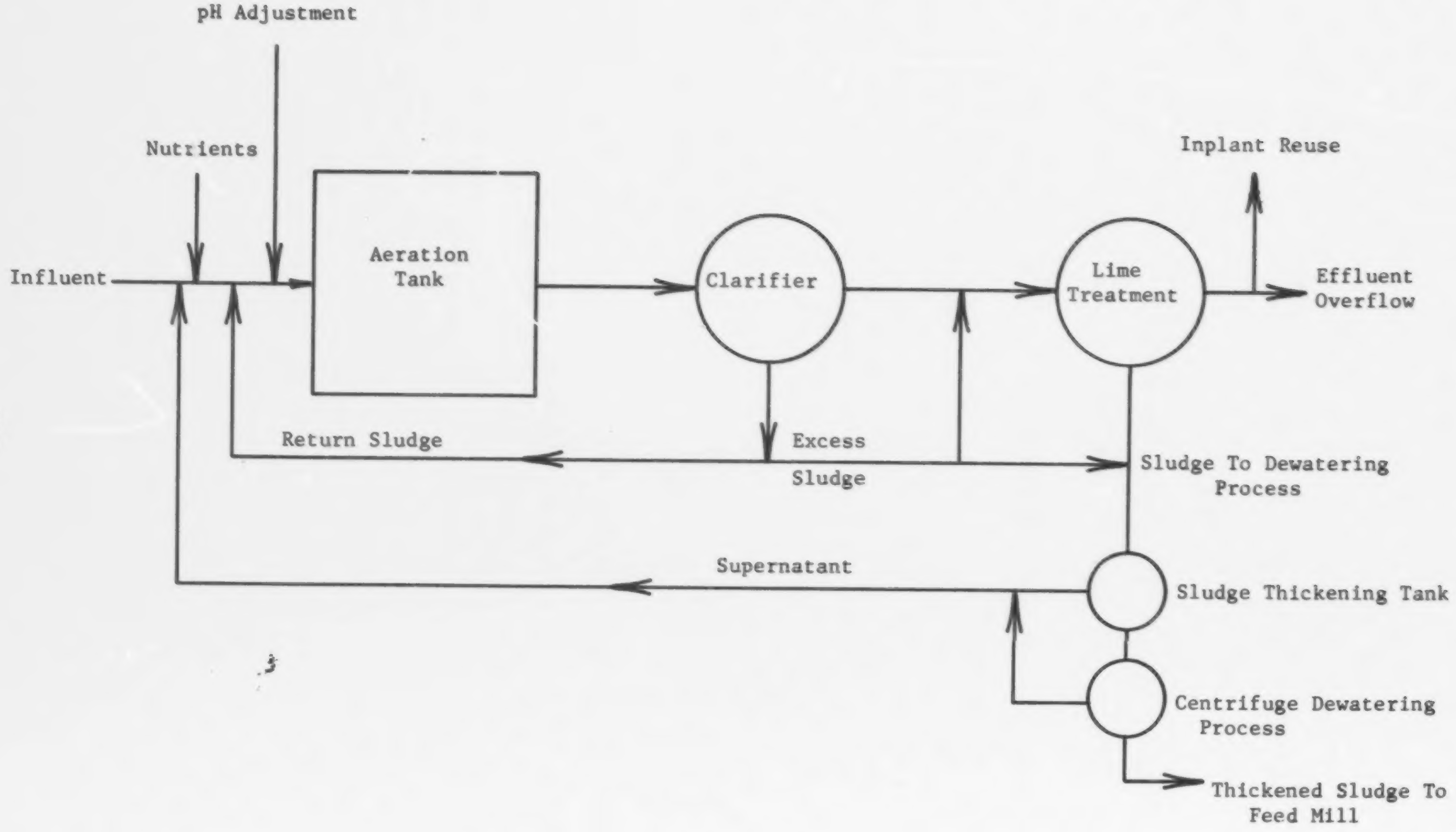
pH Adjustment
Nutrients
Influent
Aeration Tank
Clarifier
Lime Treatment
Inplant Reuse
Effluent Overflow
Return Sludge
Excess Sludge
Sludge To Dewatering Process
Supernatant
Sludge Thickening Tank
Centrifuge Dewatering Process
Thickened Sludge To Feed Mill

Figure 1. WASTEWATER TREATMENT SYSTEM

a) to determine the design and operating parameters for lime treatment of effluent from an activated sludge plant treating wastewater from a citrus processing plant;

b) to reuse the treated effluent in the processing plant;

c) to determine the efficiency of lime treatment for removal of residual organic matter including nutrients;

d) to determine the suitability of waste sludge as a cattle feed additive.

WASTEWATER FLOW AND FRUIT PROCESSED

During the 1968-1969 citrus processing season, a daily record was kept of the number of boxes of fruit processed and the volume of wastewater treated. A record was also kept of the type fruit processed. Many factors influence the amount of fruit processed in any particular day. A processing plant will operate one, two, or three shifts a day and up to seven days a week,depending on the availability of fruit. Wastewater is extremely variable throughout a processing season, and frequently on weekends there is no wastewater at all.

Data collected showed that for every box of fruit processed (90 pounds of fruit) approximately 25 gallons of concentrated wastewater were produced. This wastewater had an average BOD of 1170 mg/l; therefore, approximately 0.25 pounds of BOD for each box of fruit processed required treating.

NUTRIENT ADDITION AND CONTROL

The original waste treatment plant design called for nutrient addition in the form of anhydrous ammonia and phosphoric acid. Control of pH was to be by NaOH addition. Ammonia and phosphoric acid were added manually. It soon became evident that there was no satisfactory method to control nutrient additions due to the extreme fluctuations in hydraulic and organic loading rates. After several weeks of operation it was concluded that the most effective method of controlling nutrients would be to measure the nutrient concentration in the effluent of the activated sludge process.

Test kits were obtained which enabled the operators to determine concentrations of orthophosphate and ammonia every two hours as a means of controlling nutrient addition. These tests were made a part of the routine operation and an attempt was made to keep the ammonia and orthophosphate concentrations in the activated sludge plant below 0.5 and 1.0 mg/l, respectively. As long as the aeration time in an activated sludge process is not sufficient to convert ammonia to nitrate, then in this manner the effluent nitrogen and phosphorus can be effectively controlled.

ACTIVATED SLUDGE PROCESS

As mentioned previously, the activated sludge portion of the waste treatment plant was designed to treat 2.0 mgd with a BOD of 2000 mg/l. Aeration was to be provided by four 75 hp mechanical surface aerators in each of the two aeration tanks. Only three 75 hp aerators were provided for each tank because of the expected reduced load. Hydraulically and organically, the plant was loaded at approximately 60 percent capacity. The maximum and minimum flows to the plant were 1.5 mgd and 0.0 mgd, respectively. The maximum and minimum BOD levels applied were 3300 mg/l and 270 mg/l, respectively.

Operational problems were caused by the release of peel press liquor and water from the orange oil recovery system. Normally, all peel press liquor is evaporated down to molasses, then recovered as cattle feed. However, the evaporation capacity of the plant was stressed to a maximum, and it was not unusual to receive 25,000 to 50,000 gallons of press liquor over a short period of time. Peel press liquor has a BOD of around 60,000 mg/l and contains orange oil and d-Limonene, which are toxic to the activated sludge process and also cause foaming. In general, when a slug of peel press liquor was received, the aeration tank D.O. was lowered drastically, the S.V.I. decreased, and foaming occurred. This resulted in solids overflowing the weirs into the lime treatment tank and significantly reducing the overall plant treatment efficiency.

Foaming was perhaps the major problem experienced with the activated sludge process, occurring for a considerable portion of the citrus season and causing a reduction in treatment efficiency for both the activated sludge process as well as the lime treatment process. It was only during the latter part of the season that the major cause of foaming was determined. Water from the orange oil recovery process was being discharged into the treatment plant and this water contained a high concentration of emulsified orange oil. As soon as this waste stream was diverted to the evaporators and no excess press liquor was discharged, the activated sludge process performed exceptionally, as did the lime treatment process.

ACTIVATED SLUDGE PROCESS LOADING RATES

Figure 2 shows the variation in process loading rates during the citrus season. Loading rates varied from a minimum of 0.04 pounds BOD/pound MLSS to a maximum of 0.378 pounds BOD/pound MLSS. The average during the citrus season was 0.143 pounds BOD/pound MLSS. This loading rate was within the limits of the loading rates of the extended aeration process.

ACTIVATED SLUDGE PROCESS TREATMENT EFFICIENCY

Figures 3 and 4 show the influent BOD and the effluent BOD. As previously mentioned, the maximum and minimum BOD concentrations were 3300 and 270 mg/l, respectively, in the influent. Maximum and minimum BOD's in the effluent were 129 and 2 mg/l; however, the maximum values of 129 mg/l is probably incorrect as only two 24-hour composites of the effluent had BOD concentrations greater than 100 mg/l.

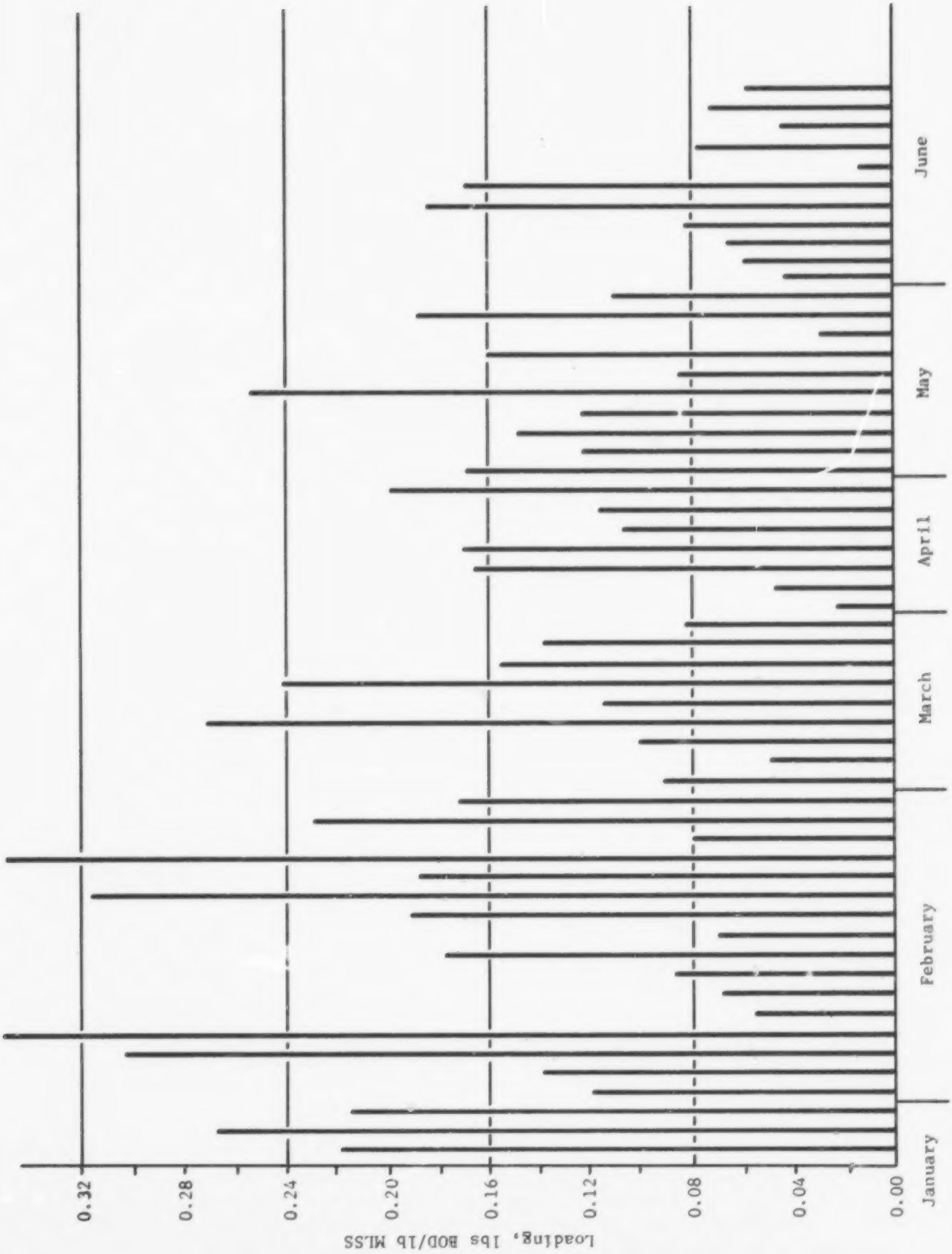

Figure 2. ACTIVATED SLUDGE LOADING RATES

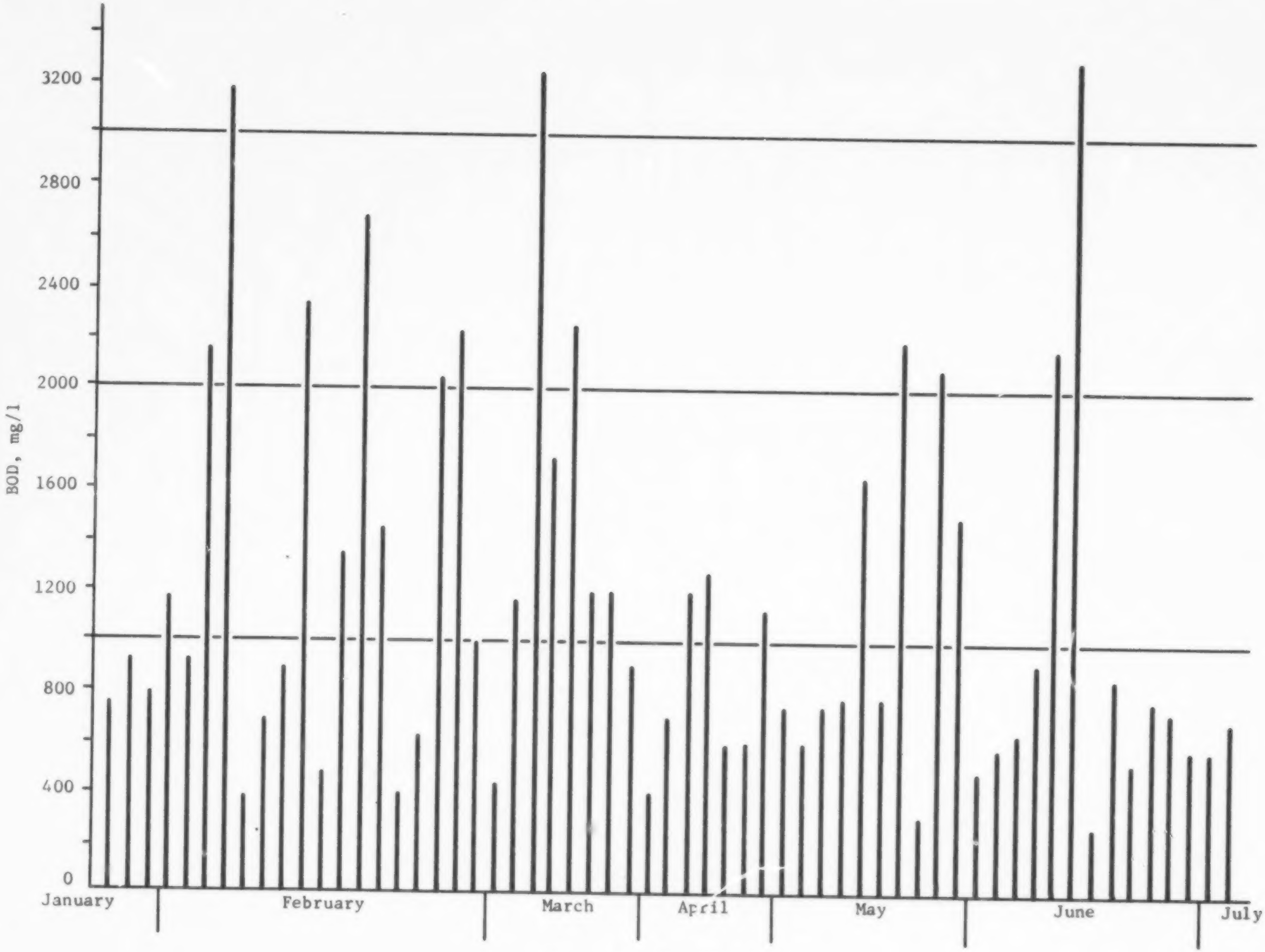

Figure 3. INFLUENT BOD

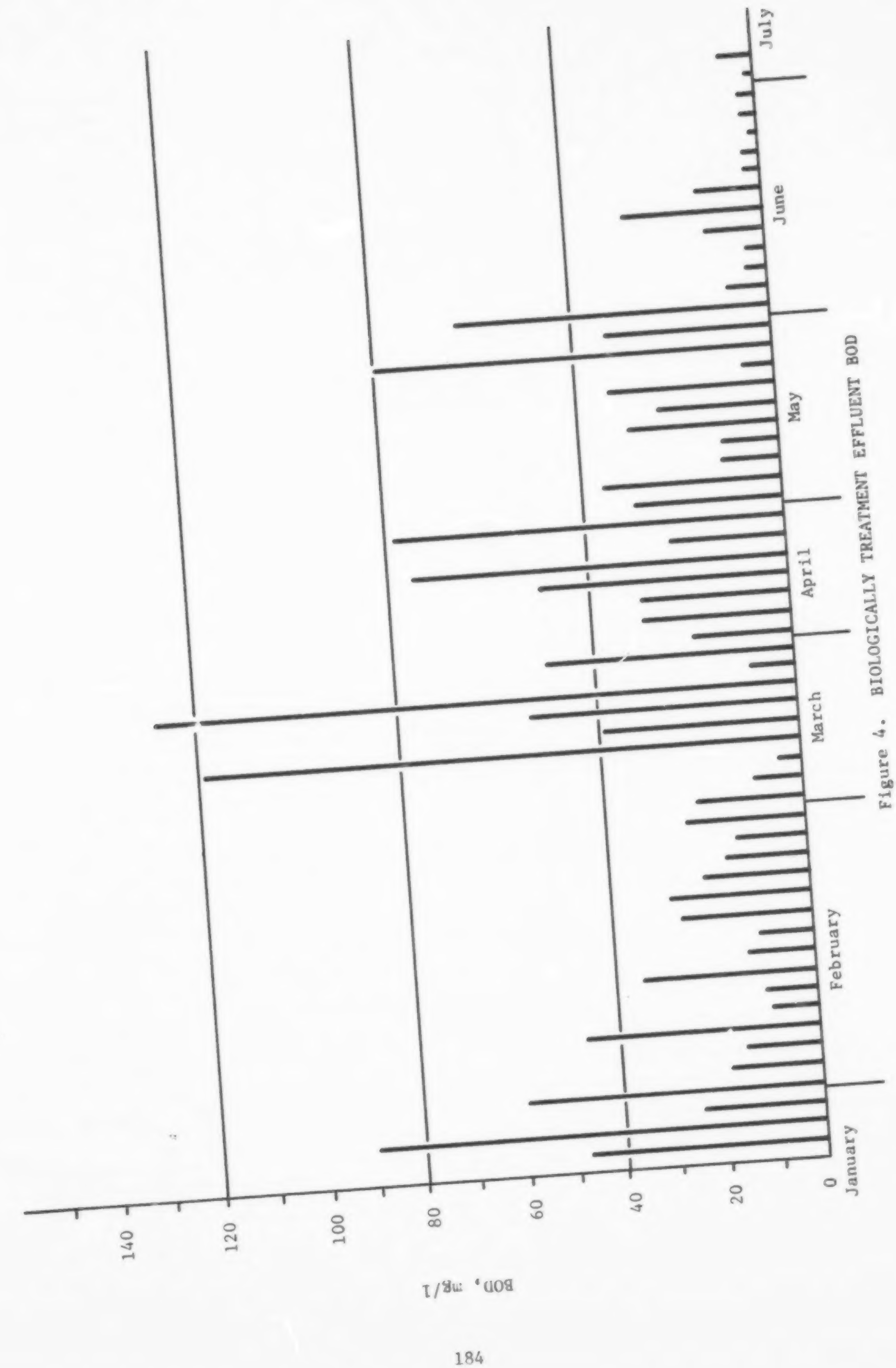

Figure 4. BIOLOGICALLY TREATMENT EFFLUENT BOD

The average BOD of the influent was 1170 mg/l for the complete citrus processing season, while the effluent BOD averaged 30 mg/l during the same period. This is an average BOD reduction of 97.5 percent for the complete season. It should be kept in mind that many operational problems were experienced during the season which actually decreased the efficiency of the treatment plant. The actual capabilities of the plant were demonstrated the latter part of the season when the foaming problem had been solved by removing the wastewater containing orange oil. Data collected during the period from June 4, 1969, through July 2, 1969, showed BOD values of the influent averaged 1000 mg/l during these four weeks, and BOD values of the effluent averaged 7 mg/l during the same period. This is a treatment efficiency of 99.3 percent.

LIME TREATMENT PROCESS - OPERATION PROBLEMS

There was a variety of operation problems associated with the lime treatment tank. The lime treatment unit was initially designed to remove all waste activated sludge with the precipitated $CaCO_3$ sludge. The only problem with this was the fact the lime sludge was much heavier than the waste activated sludge; therefore, it settled to the bottom of the lime tank. If solids were removed fast enough to keep the activated sludge from going over the weirs, all of the lime sludge was quickly removed leaving no lime sludge blanket. This problem was solved by wasting the excess activated sludge directly to the wet well where the lime sludge was wasted. The two sludges mixed and were then pumped to the citrus processing plant for recovery as cattle feed.

Although activated sludge was not intentionally discharged to the lime tank after the first few weeks of operation, unintentional discharge of solids occurred during most of the citrus season, with the exception of the last few weeks of operation. The main reason for this was the foam carry over from the aeration tanks. The inability to produce a clear effluent was the major result of this solids carry over. This significantly affected the treatment efficiency of the lime treatment process. Only during the last few weeks of operation, after the wastewater containing orange oil was removed from the treatment plant, did the lime tank produce an acceptable and clear effluent.

A series of coagulant aids was tested. Starch proved to be useless because of the high concentration of activated sludge solids entering the lime tank. Alum was used with similar results. Only after using lime alone was any significant result obtained in settling wastewater containing high concentrations of activated sludge. No problem was experienced with obtaining a clear effluent as long as the effluent from the sludge clarifier contained a low solids concentration.

TREATMENT EFFICIENCY OF THE LIME UNIT FOR BOD, COD AND SOLIDS REMOVAL

Judgment of the efficiency in lime treatment of an activated sludge effluent cannot be based on the chemical data obtained during the complete citrus season. This is because the waste treatment plant was not operating properly on a continuous basis until the last few weeks of the citrus season. Only after the foaming problem was solved and the amount of activated sludge solids entering the lime treatment unit was reduced could the data be considered as representative of a properly operating unit.

Tabulated below are the average influent and effluent nutrient analyses for the complete citrus season and for the period June 4 through June 12.

	Total Citrus Season		June 4-June 12	
	mg/l as N or P			
	Influent	Effluent	Influent	Effluent
Total N	3.80	4.95	2.55	1.88
Ammonia N	0.49	0.69	0.84	0.25
Organic N	3.14	4.28	1.78	1.60
NO_3+NO_2	0.04	0.05	0.03	0.01
NO_2	0.01	0.01	0.01	0.00
NO_3	0.02	0.03	0.02	0.01
Total P	3.20	2.10	2.33	0.46
Ortho P	1.23	0.67	2.07	0.30
Total P (filtered)	1.20	0.69	1.26	0.16
Ortho P (filtered)	0.75	0.25	0.97	0.11

The effect of foaming and carry over of solids was most pronounced for the nitrogen determinations. The fact that the effluent nitrogen concentrations were higher than the influent concentrations can be attributed to the sampling method. All nutrient analyses on the influent were run on a settled sample. This in effect removed most of the solids associated with foam carry over. Nutrient analyses on the effluent were made on the complete sample, which included all solids not effectively removed in the lime treatment unit. Due to the quantity of activated solids going into the lime unit during a considerable portion of the citrus processing season, it is probable that a portion of these solids were placed into fine colloidal form or into solution due to the mechanical interaction of the lime solids. This would also account for higher nitrogen concentrations in the effluent than the influent.

Lime tank total influent phosphorus concentrations averaged 3.20 mg/l while effluent concentrations averaged 2.10 mg/l during the complete citrus processing season. This is a removal efficiency of only 34 percent. Again, the main reason for this lower removal efficiency was the foaming problem. During the period June 4 through June 12, influent total phosphorus concentrations averaged 2.33 mg/l and effluent concentrations averaged 0.46 mg/l. This is a treatment efficiency of 80 percent. However, the use of lime treatment for phosphorus removal in an activated sludge effluent containing only 2.5 mg/l of phosphorus is not economically justifiable.

REUSE OF LIME TANK EFFLUENT IN-PLANT

Effluent from the treatment plant was successfully reused in-plant for considerable periods of time. Reuse was limited to use as barometric leg water for two reasons. Primarily, the pH from a lime treatment unit will cause deposition of $CaCO_3$ in pipes and on equipment unless the pH is lowered much closer to the pH_s. Secondly, extensive piping changes would be required to reuse the water for cooling purposes in the citrus processing plant.

There is no question that the lime treated effluent can be reused as barometric leg water and cooling water at Winter Garden Citrus Products Co-op. by simply adjusting the pH with CO_2 and installing the required piping. The only problem is that presently it is cheaper and easier to pump well water from the abundant supply than reuse the waste treatment plant effluent.

CENTRIFUGE OPERATION

Centrifuge operation was one of the weakest points in the overall treatment efficiency of the plant. Overall efficiency of any treatment plant depends greatly on removal of waste sludge from the system, in this case, for recovery as cattle feed. Thickening the waste sludge was necessary to prevent overloading of the rotary dryers. Therefore, a centrifuge was installed for the thickening operation.

The centrifuge never operated to complete satisfaction during the entire citrus season, the main problem being inability to keep it in continual operation because of shear pin failure due to overloading. Early in the season a major mechanical failure occurred in the centrifuge and it had to be rebuilt.

One of the main factors contributing to the poor performance of the centrifuge was that the entire treatment plant design was based on parameters developed during a six-week laboratory study. No pilot plant studies were performed; therefore, there were no firm parameters by which to design the centrifuge. Another major problem was the variability in the waste sludge entering the centrifuge. Waste sludge from the treatment plant was pumped to a holding tank in the citrus processing plant before it was centrifuged. The variation of the solids from this surge and thickening tank was considerable. Lime solids tended to separate from the activated sludge solids and settle to the bottom. After a period of time when no solids had been withdrawn, the solids concentration increased to as high as 10 to 12 percent. A sudden slug of this material invariably sheared a pin in the centrifuge. Even after a fairly consistent solids concentration was fed to the centrifuge, it was difficult to keep it continuously operating.

The manufacturer spent considerable time trying to get the machine to perform properly. Finally, toward the latter part of the season, the centrifuge rpm was reduced, and this seemed to be the answer for continuous operation.

The inability of the centrifuge to operate properly meant that solids could not be wasted as desired. When the centrifuge was out of operation, thickened solids from the bottom of the surge tank were put directly on the citrus peel for drying. This increased the amount of water going to the dryers, which were already loaded to a maximum. As a result, solids built up in the waste treatment plant, compounding the foaming problem.

Almost all of the waste sludge from the treatment plant was recovered as cattle feed. This meant that several hundred tons of waste solids were included with the citrus peel and recovered as cattle feed. All of this feed has been sold and consumed by cattle. It should be kept in mind that the waste sludge represented only about three tons out of a total 350 tons of cattle feed produced each day. Therefore, it was ultimately only a fraction of the entire cattle feed production.

CONCLUSIONS

1. The complete mixed activated sludge process will treat wastewater from the citrus processing industry with an efficiency greater than 99 percent.

2. All waste sludge can be reclaimed along with the pressed citrus peel as cattle feed.

3. Effluent from the waste treatment system can be reused in the citrus processing plant.

4. Effluent nitrogen and phosphorus concentrations can be more effectively controlled by controlling the addition of nitrogen and phosphorus to the influent wastewater than by attempting to lime treat the activated sludge effluent while adding an excess of nutrients to the influent.

5. Addition of large quantities of orange oil and peel press liquor into the activated sludge process will completely disrupt the treatment efficiency and cause heavy foaming.

6. High production of excess solids is one of the key factors to be considered when treating citrus waste by the activated sludge process.

SEAFOODS PROCESSING: POLLUTION PROBLEMS AND GUIDELINES FOR IMPROVEMENT

by

M. R. Soderquist, K. J. Williamson, and G. I. Blanton*

ABSTRACT

This paper contains discussions of the processing of the major United States seafoods species, the resultant wastewater strengths and flows, solid wastes magnitudes, current treatment and by-product recovery methods, and current and recommended research in water pollution abatement. The paper was based on a comprehensive literature review and extensive on-site investigations of current research, processing, and treatment activities in the major seafoods centers of the U.S. The reader desiring an exhaustive review of the entire industry, including all major species commercially harvested in the United States, is directed to reference number 1 at the back of this paper.

This study was supported by the Federal Water Quality Administration, U.S.D.I., through Grant Number 12060ECF. Major assistance in the national survey segment of the investigation was provided by the National Canners Association and the U.S. Bureau of Commercial Fisheries.

INTRODUCTION

The present world marine harvest stands at approximately 50 million tons per year. Ninety percent of this catch is fish, the remainder being whales, crustaceans and mollusks. From 1850 to 1950, this harvest increased at an average rate of 2.5 percent per year. During the last two decades this increase has jumped to 5 percent per year (2). Some observers believe that even with present methods of fishing, the yield can be increased to 5 to 10 times the present value. More conservative analysts estimate a possible increase of 2 to 3 times the present yield (3).

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The increased catches of the 1950's and 1960's were due mainly to the intensified fishing efforts of a few nations: Peru, Japan, and the Soviet Union. The annual United States catch, meanwhile, has been steadily declining; since 1962 U.S. fish harvests have decreased 20 percent. The most common reasons cited for this decrease are low efficiencies, insufficient and expensive labor, and governmental restrictions (4). Based on recent performance, the United States seafoods industry is not expected to expand significantly in the near future.

The annual U.S. catches average approximately 6 billion pounds (5). The fish are utilized as follows: 35 percent rendered, 30 percent marketed fresh, 20 percent canned, 10 percent frozen, and 1 percent cured (6). Frozen fish products have been increasingly popular items; a 150 percent increase in frozen fish sales over the next 15 years has been predicted (7).

The U.S. consumption of fishery products has continued to rise, as shown on Figure 1. These increasing demands, however, have been satisfied by imported products. This increase in consumption has been almost exclusively due to the population increase; the U.S. per capita consumption of seafood products has remained at approximately 11 pounds per year over the last 20 year (5).

A significant portion of the fishes and shellfishes processed is wasted. The percentage of each species wasted ranges from 0 percent for fish which are completely rendered (e.g., menhaden) to 85 percent for some crab (e.g., blue crab). The average wastage figure for all fish and shellfish is about 30 percent. In addition to these large volumes of solid wastes, significant wastewater flows result from the butchering, washing and processing of the products. The volumes of solids and wastewater vary widely with seafoods and processing methods.

Using the 30 percent figure, the total annual volume of solid wastes generated in the seafoods industry in the United States is roughly 1.2 billion pounds. A large portion of these wastes is rendered for animal feed. The remainder is taken to municipal or private disposal sites or discharged directly to adjoining waters. The pollutional strength per pound of fish waste has been estimated to be 0.2 pounds of five-day biochemical oxygen demand (BOD_5), or approximately one daily population equivalent (8). As will be discussed later, this figure is highly variable and probably represents only the carbonaceous demand, neglecting the nitrogenous demand which would be exerted somewhat later. Using this figure and assuming that 50 percent of the fish wastes, as an average, are rendered, the population equivalent of this industry can be estimated to be 2 million people. The population equivalent of solid and liquid fish processing wates has been estimated

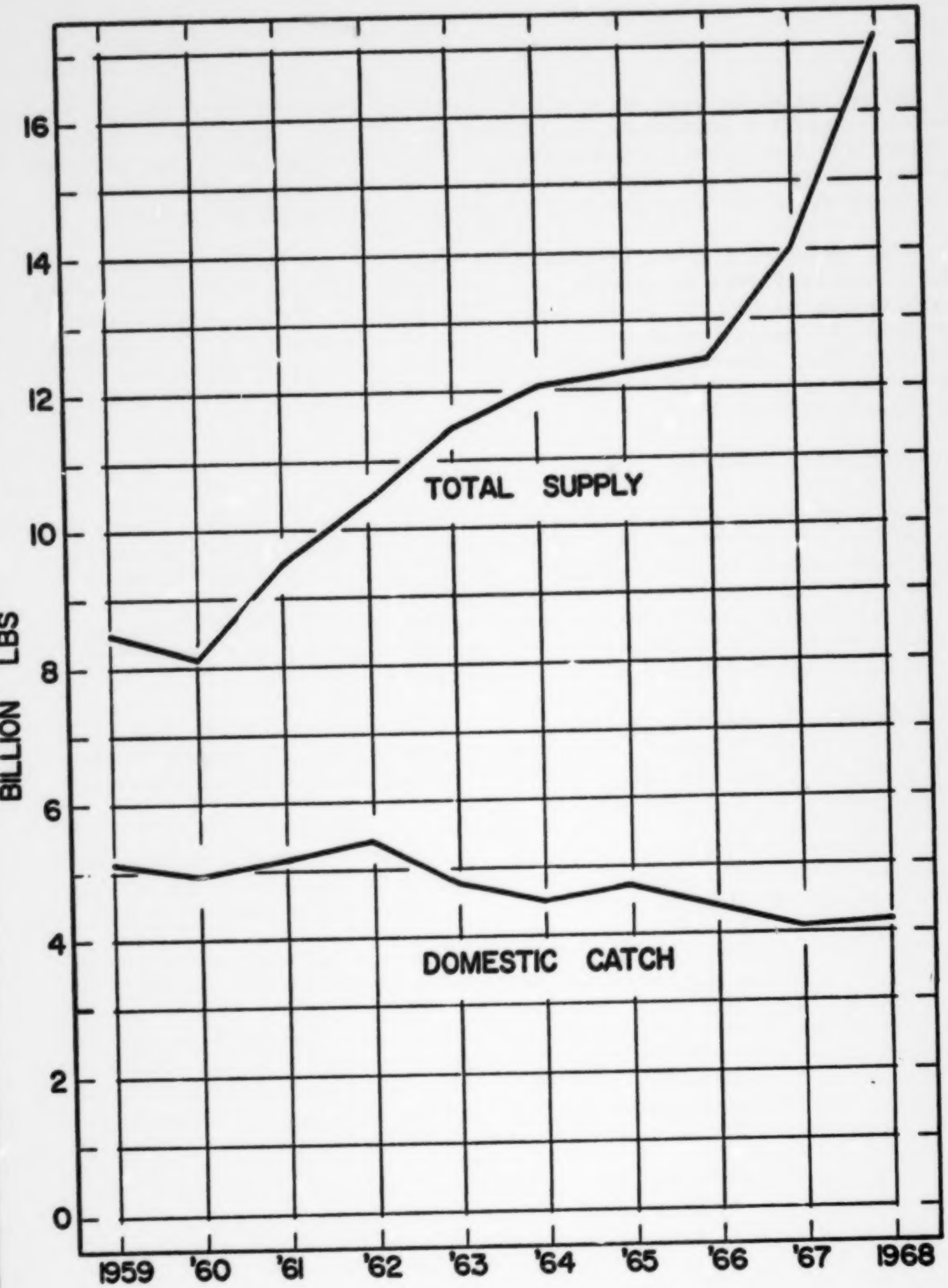

FIGURE I SEAFOODS CONSUMPTION IN THE U.S. (5)

by one author to be from 66 to 1020 per ton of fish (9). For the U. S., this represents a population equivalent of 0.23 to 3.6 million. These figures are deceptively conservative, for a major segment of the seafoods production takes place during short seasons, intensifying the problem. The industry is not typified by a constant output month after month.

The fish processing waste problem has become serious in certain areas. Waste treatment will be necessary in the future to meet Federal and state water pollution control regulations. The purpose of this study was to evaluate the present state of the art of fish processing waste treatment and by-product recovery and to suggest research necessary to advance this technology to meet future needs. Only six major U. S. seafoods categories are considered here.

THE INDUSTRIAL FISHERIES

Menhaden, herring, and alewives are oily fishes which comprise the bulk of the "industrial fisheries" in this country: the rendering of whole fish into meal, oils, and solubles. The meal is used primarily as animal feed and fertilizer; the oil becomes an ingredient in paints, varnishes, resins, and similar meterials, is added to animal feed, or is used for human consumption abroad; and the solubles are either fed directly to animals or are dried and processed into meal.

The menhaden fishery is the largest in the United States; the 1968 catch totaled 1.4 billion pounds (5). The industry is located mainly in the middle Atlantic and the Gulf states. Fishing takes place predominantly during the summer and fall months.

In many cases, the menhaden rendering operations are highly mechanized. The process, outlined schematically on Figure 2, involves first the harvesting of the fish in purse seines and storage in the holds of the fishing boats. Ice or refrigeration is used for preservation if the trip exceeds one day. At the plant, the fish are pumped from the holds, washed, automatically sprayed and conveyed into the plant. Cooking is done continuously by steam. The fish are then pressed to remove the oil and most of the water. This presswater is screened to remove solids and centrifuged to separate the oil. The remaining water, called stickwater, is discharged or evaporated to produce condensed fish solubles. The solid residual from which the water and oil have been pressed is known as press cake. The press cake is dried to about 10 percent moisture and then ground for fish meal.

Since the menhaden fishing areas are presently largely exploited to the maximum, significant future growth in this industry is not anticipated. Continuous production at levels near those of recent years is expected.

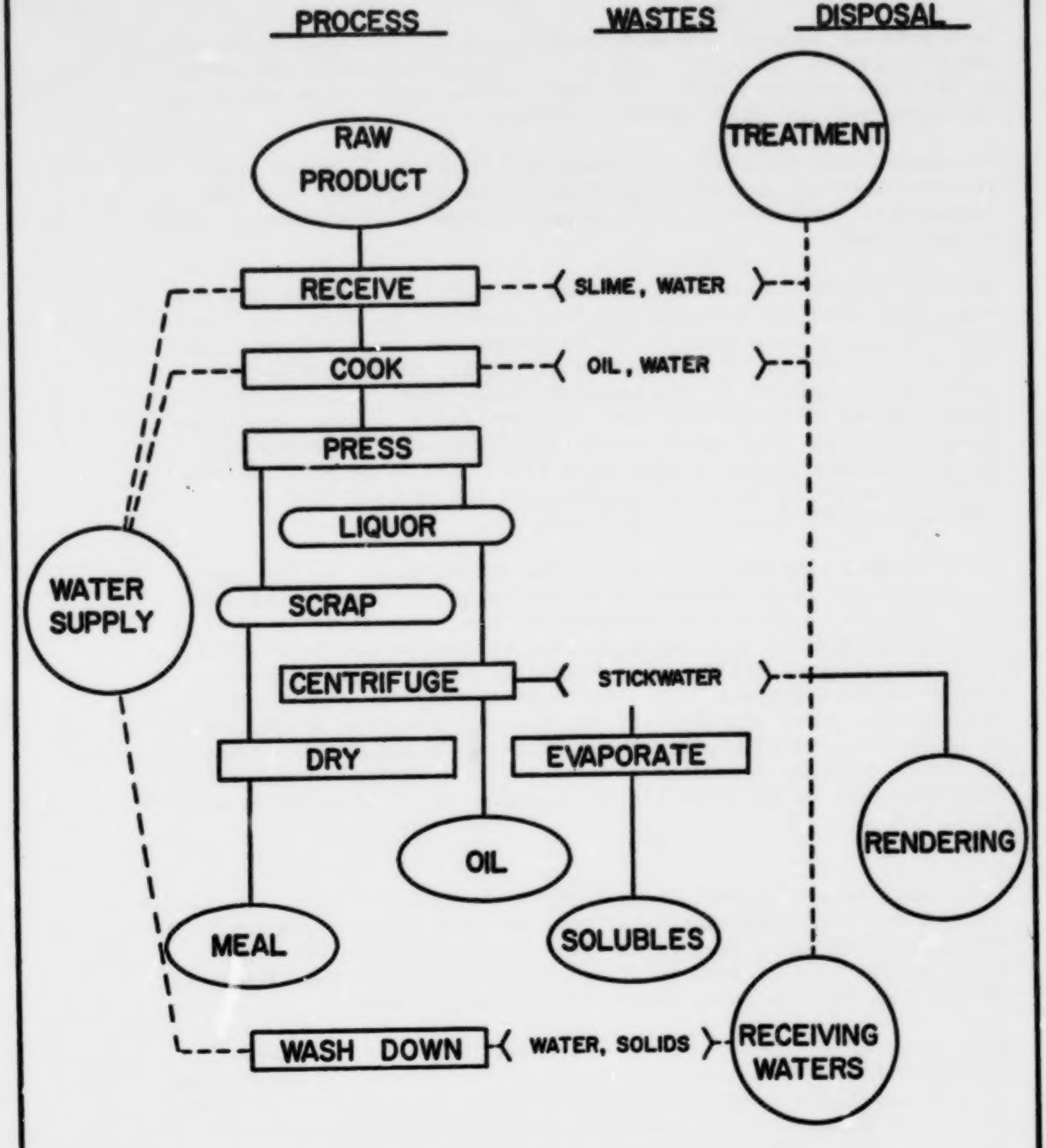
PROCESS
WASTES
DISPOSAL
RAW PRODUCT
TREATMENT
RECEIVE
SLIME, WATER
COOK
OIL, WATER
PRESS
LIQUOR
WATER SUPPLY
SCRAP
CENTRIFUGE
STICKWATER
DRY
EVAPORATE
RENDERING
OIL
MEAL
SOLUBLES
WASH DOWN
WATER, SOLIDS
RECEIVING WATERS

FIGURE 2 MENHADEN RENDERING

In a properly managed menhaden rendering plant, the quantities of wastes produced are small. The only inherently troublesome waste is the fish pumping water. The other wastes result from spills and leakages, both of which can be minimized.

The wastewaters from the production of fish meal, solubles, and oil from herring, menhaden and alewives can be divided into two categories: high-volume, low-strength wastes and low-volume, high-strength wastes.

The high-volume, low-strength wastes consist of the water used for unloading, fluming, transporting, and handling the fish plus the washdown water. One author (10) estimated the fluming flow to be 200 gallons per ton of fish with a suspended solids loading of 5,000 mg/l. The solids consisted of blood, flesh, oil and fat. These figures vary widely; other authors listed herring pump water flows of 250 gpm with total solids concentrations of 30,000 mg/l and oil concentrations of 4000 mg/l (11). The bilge water in the boat was estimated to be 400 gallons per ton of fish with a suspended solids level of 10,000 mg/l.

The strongest wastewater flows are the stickwaters. In the past, stickwater was often discharged to the receiving waters, but now this practice is generally forbidden by law. One reference listed the average BOD_5 of stickwater as ranging from 56,000 to 112,000 mg/l, with average solids concentrations, mainly proteinaceous, ranging up to 6 percent (12). Fortunately the fish processing industry has found the recovery of fish solubles from stickwater to be at least marginally profitable. In most instances, stickwater is now evaporated to produce condensed fish solubles. Volumes have been estimated to be about 120 gallons per ton of fish processed (13).

TUNA

Tuna ranks as the number one seafood in the United States. Americans consume over one billion cans of tuna per year (14). Tuna are large migratory fish which feed on smaller macroscopic sea life. Their distribution in the ocean is still largely unknown. The largest part of the tuna harvest takes place off the Pacific Coast.

Most tuna canned in the United States are caught in relatively distant waters. A modern tuna vessel can hold from 150 to 300 tons of fish and has a range of 1,000 miles (15). Because of the length of time in transport, the fish are normally frozen on board the vessels. After the boat arrives at dockside, the tuna canning operation, as shown on Figure 3, begins with the mechanical unloading of the fish, which are weighed and inspected while they are still frozen.

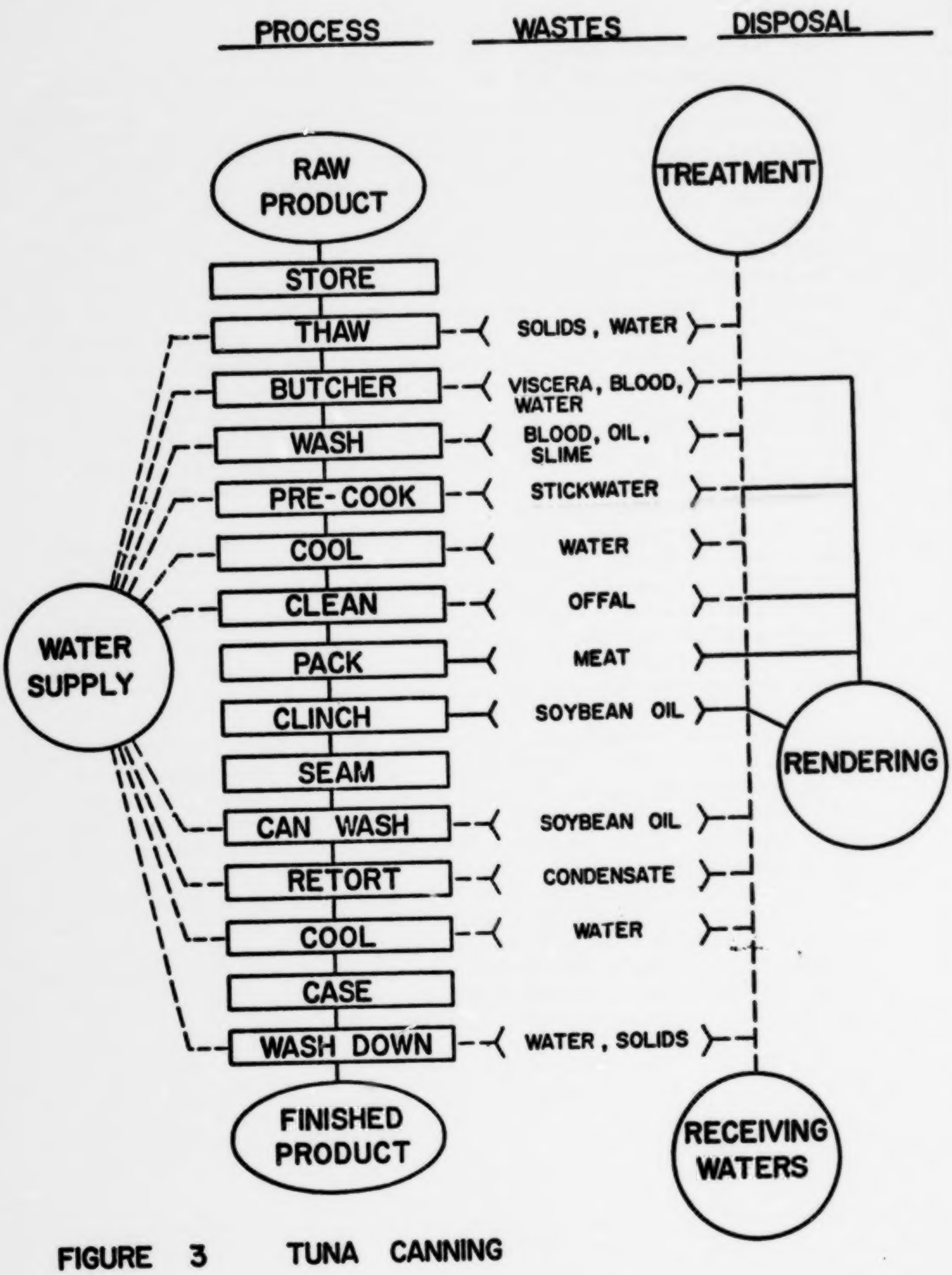
PROCESS
WASTES
DISPOSAL
RAW PRODUCT
STORE
THAW
BUTCHER
WASH
PRE-COOK
COOL
CLEAN
PACK
CLINCH
SEAM
CAN WASH
RETORT
COOL
CASE
WASH DOWN
FINISHED PRODUCT
WATER SUPPLY
SOLIDS, WATER
VISCERA, BLOOD, WATER
BLOOD, OIL, SLIME
STICKWATER
WATER
OFFAL
MEAT
SOYBEAN OIL
SOYBEAN OIL
CONDENSATE
WATER
WATER, SOLIDS
TREATMENT
RENDERING
RECEIVING WATERS

FIGURE 3 TUNA CANNING

Then the tuna are thawed. The next step, evisceration, is normally conducted by hand in several phases. The body cavities are flushed with water and all adhering viscera carefully removed. The viscera are used for fish meal or pet food and the livers are sometimes recovered for oil and vitamins. After butchering, the fish are steam precooked. The time of cooking varies with the fish size, but it is usually about three hours. This cooking removes 22 to 26 percent of the moisture (15). Following cooking, the fish are cooled for approximately 12 hours to firm the flesh. The meat is then separated by hand from the head, bones, fins and skin. All dark meat is removed and usually recovered for pet food. The light meat for canning is placed on a conveyor belt and transferred to the "Pak-Shaper." Tuna slices are arranged lengthwise in the Pak-Shaper which then molds the meat into a cylinder, fills the cans and trims the meat after filling. Each machine has a capacity of from 125 to 150 cans per minute (15). Prior to vacuum sealing, salt and vegetable oils are added to the cans. After sealing, the cans are retorted by standard procedures.

The annual tuna catch averages approximately 300 million pounds, almost all of which is canned. The U.S. catch in recent years has failed to meet the increased domestic market. Use of scientific methods to determine fish migration should increase future catches and enable the domestic market to expand. A slight upward trend in tuna production has been evident now for the past six years and is expected to continue (16).

It has been estimated that 65 percent of the tuna is wasted in the canning process (17). Using this figure, the 1968 quantity of wastes generated in the United States was calculated to be 190 million pounds. The degree of wastage probably varies somewhat with species. A recent study examined in detail the waste from a tuna canning and by-product rendering plant for a five-day period (18). The average waste flow was found to be 6800 gallons per ton of fish. Organic loadings varied from 500 to 1550 mg/l BOD_5. The average daily COD ranged from 1300 to 3250 mg/l and the total solids averaged 17,900 mg/l of which 40 percent was organic. The mean values and their expressions in terms of pounds per ton of fish are listed on Table 1.

Table 1. Tuna Waste Characteristics (18)

Parameter	Mean Concentration mg/l	Mean Concentration lbs/ton of fish
COD	2,273	129
BOD_5	895	48
Total Solids	17,900	950
Suspended Solids	1,081	58
Grease	287	15

These figures indicate that the five-day BOD of the tuna waste was only approximately 40 percent of the COD value. Due to the high proportion of particulate matter in the total solids (leading to low surface-area-to-volume ratios), and to the organic nature of the wastes, a considerable BOD is exerted after five days. In this case, at 22 days, the BOD exerted was 3520 mg/l and was noted to still be rising. It is important to realize that the waste exerts a considerable nitrogenous demand (that oxygen required to oxidize the less reduced forms of nitrogen to nitrate) in excess of the five-day carbonaceous value.

SALMON

The only significant commercial anadromous fishery in the United States is the salmon fishery. The five main species harvested in this country are chinook (king), sockeye (red), silver (Coho), pink and chum. The major portion of the catch is canned.

The fish are caught fairly close to the canneries and are often stored in the boats without refrigeration. Canning operations are conducted for the most part employing standard cannery equipment in a conventional manner as shown on Figure 4. After transfer from the holds of the fishing boats, the fish are eviscerated, beheaded and the fins removed. The raw meat, including the bones, is then placed into cans, the cans are weighed, and their weights are adjusted (if necessary) prior to sealing. The cans are then seamed, retorted, cooled and cased prior to shipping.

The principal exception to this standard canning operation is the use, predominantly in Alaska, of the "iron chink". The iron chink performs several functions in one operation, removing heads, fins and viscera mechanically.

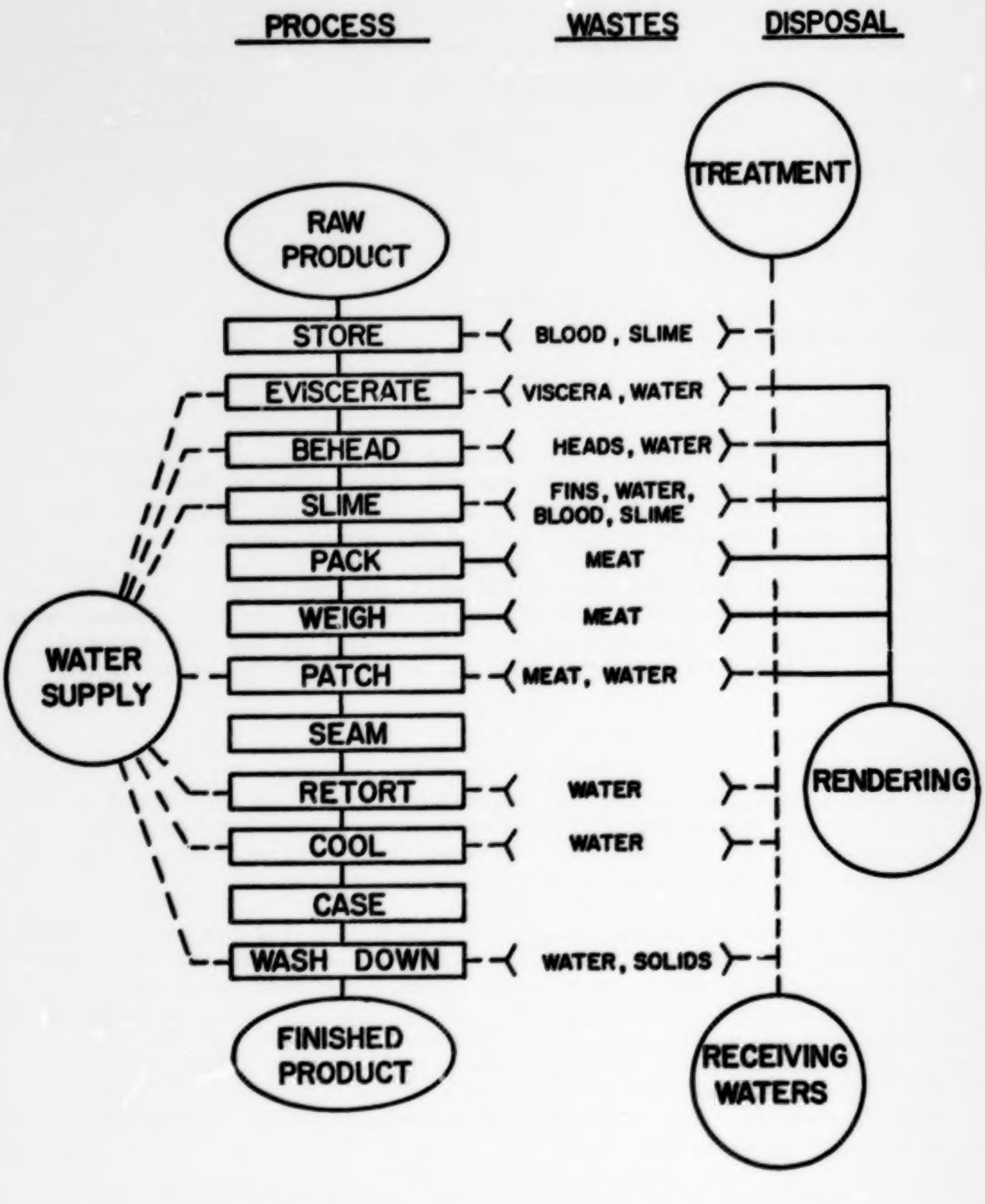
PROCESS
WASTES
DISPOSAL
TREATMENT
RAW PRODUCT
STORE
BLOOD, SLIME
EVISCERATE
VISCERA, WATER
BEHEAD
HEADS, WATER
SLIME
FINS, WATER, BLOOD, SLIME
PACK
MEAT
WEIGH
MEAT
WATER SUPPLY
PATCH
MEAT, WATER
SEAM
RETORT
WATER
RENDERING
COOL
WATER
CASE
WASH DOWN
WATER, SOLIDS
FINISHED PRODUCT
RECEIVING WATERS

FIGURE 4 SALMON CANNING

The total 1968 salmon catch was 301 million pounds compared with the average over the previous five years of 335 million pounds per year (5). The harvesting is centered around Alaska with significant contributions from Washington and Oregon.

The Pacific salmon fishery is now advancing after a general failure which occurred in 1967. The future of this industry is largely dependent on market conditions, pressure from foreign competitors and on future conservation practices. A major expansion of the salmon industry in this country is not anticipated. Continued production at or near current levels is expected (5).

The quantities and possible uses of salmon wastes have been rather thoroughly researched. One investigating team (19) found salmon processing to produce 34 percent waste. Similar estimates were reported by other sources: 33 percent (20), 27 percent (21), and 30-35 percent (17). The Bureau of Commercial Fisheries (22) listed waste fractions by species as: chinook, 30 percent; red, 33 percent; Coho, 33 percent; pink, 35 percent and chum, 33 percent. Using the BCF values of wastage and total catch (5), waste volumes were calculated to be as shown on Table 2.

Table 2. Calculated Salmon Waste Quantities, 1968

Species	Wastage (%)	Quantity (lbs x 10^6)
Chinook	30	7
Chum	33	26
Pink	35	36
Red	33	18
Coho	33	12
Total		100

Of these wastes, from 50 to 61 percent (depending on species) consists of heads and collars. Another 11 to 16 percent is made up of tails and fins. Other waste segments in decreasing order of magnitude are: liver, roe, milt, digestive tract and heart (23).

Claggett and Wong (11) listed the flow from a salmon canning line at 300 gallons per minute with a total solids concentration of 5,000 mg/l and oil concentration of 250 mg/l. Other investigators have characterized the wastes from salmon canning operations as shown on Table 3.

Table 3. Salmon Processing Waste Strengths

Process	Flow (mgd)	COD (mg/1)	BOD_5 (mg/1)	BOD_5/raw product (lbs/ton)	Suspended Solids (mg/1)	Total Solids (mg/1)	Volatile Solids (mg/1)
Canning (24)	0.043-0.046	5,920	3,780	65.2-178.2	508-4,780	1,188-7,444	1,048-7,278
Mild curing (24)	0.015-0.066	--	173-1,320	10.2-80.0	44-456	258-2,712	98-2,508
Mild curing and fresh (24)	0.011-0.036	--	206-2,218	3.3-36.0	112-820	484-2,940	84-1,756
Mild curing and fresh (24)	0.014-0.046	--	397-3,082	3.8-18.6	40-1,824	88-3,422	67-2,866
Caviar (24)	---	--	270,000	--	92,600	386,000	292,000
Canning (25)	0.33	--	3,680	--	2,470	--	--

The values for all parameters are quite variable, the wastewater strength probably depending on the efficiency of solids removal. The BOD_5 concentrations ranged from 200 to 4,000 mg/l; suspended solids, 40-5,000 mg/l; total solids, 80-8,000 mg/l; and volatile solids 60-7,000 mg/l.

Caviar production often takes place with salmon canning. This process results in extremely strong wastes, but the flows are small.

SHRIMP

The shrimp industry is the most important seafood industry of the Gulf of Mexico and South Atlantic areas. It is also significant along the Pacific Coast. The season runs from April to early June and again from August to early October (26).

Shrimp are caught commercially in otter trawls in the coastal waters. The shrimp are separated from the trash fish and stored by various methods. When short storage times will suffice, no preservation methods are used; the shrimp are taken directly to a processing plant or to a wholesale marketing vessel. When longer storage times are necessary, the shrimp are iced in the holds. In some places, notably in the Gulf of Mexico area, the shrimp are beheaded at sea and the heads dumped overboard. The heads contain most of the active degradative enzymes, so this practice retards spoilage. If the shrimp are beheaded within 30 minutes after being caught, the intestinal veins are usually removed with the heads, which is desirable from a quality standpoint.

The shrimp are unloaded from the vessels into a flotation tank at dockside to remove the packing ice and then conveyed to a rotary drum to remove surplus water and bits of debris. This is followed by weighing. In Texas and the South Atlantic states particularly, the shrimp are iced after the initial preparation to optimize peeling conditions.

Next the shrimp are peeled (or picked) by hand or machine. Machine-peeled shrimp are used mostly for canning (21). The machine-peeled shrimp are paler in color, have a poorer flavor and have a texture inferior to hand-picked shrimp. These disadvantages are offset by the fact that an automatic peeler can handle 500 pounds of shrimp per hour compared to average rates of 100 to 400 pounds of shrimp of shrimp per day per man for hand picking (26).

After peeling, the meats are inspected and washed. They are then blanched in a salt solution for about 10 minutes and dried by various methods to remove surface water. Again the shrimp are inspected and then canned. The mechanical peeling process is outlined on Figure 5.

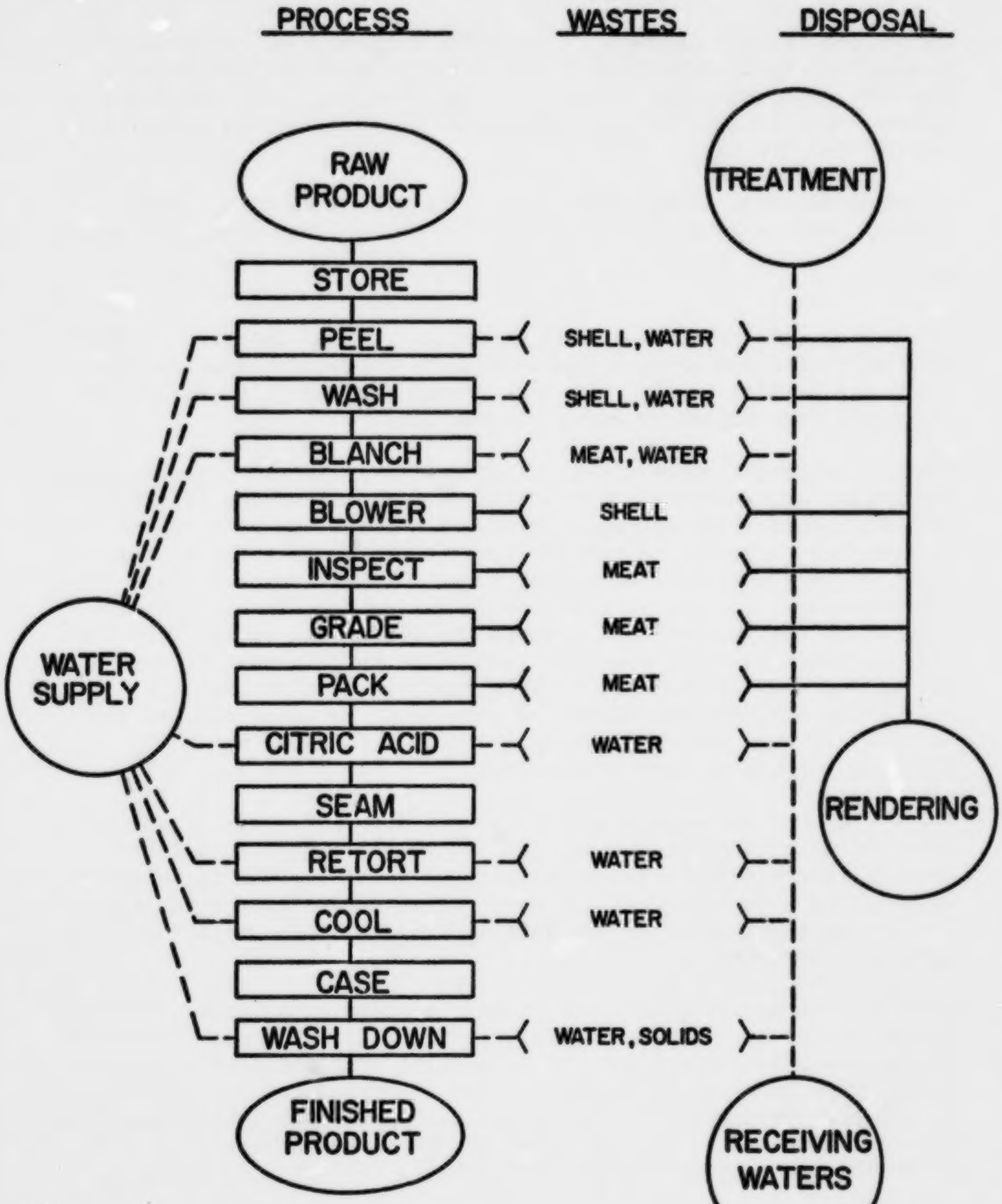
PROCESS
WASTES
DISPOSAL
RAW PRODUCT
STORE
PEEL
WASH
BLANCH
BLOWER
INSPECT
GRADE
PACK
CITRIC ACID
SEAM
RETORT
COOL
CASE
WASH DOWN
FINISHED PRODUCT
WATER SUPPLY
SHELL, WATER
SHELL, WATER
MEAT, WATER
SHELL
MEAT
MEAT
MEAT
WATER
WATER
WATER
WATER, SOLIDS
TREATMENT
RENDERING
RECEIVING WATERS

FIGURE 5 MECHANICAL SHRIMP PEELING

Shrimp are marketed fresh, frozen, breaded, canned, cured and as specialty products. An increasing amount are sold breaded or fresh-frozen, whereas the quantities of canned shrimp produced in recent years have been relatively constant. About 40 percent are sold frozen in the shell (27).

The shrimp fishery in terms of total value is the most important in the United States. In 1968, the catch exceeded 290 million pounds with a value of approximately 110 million dollars. Currently the most important finished products are frozen and breaded shrimp. In 1968, these two products comprised 92 percent of the market. Both of these products were successfully developed during the 1950's and markets are apparently continuing to expand.

Except in Alaska, the catch areas appear to be fully exploited. Yearly variation in catch seems to be dependent on the survival of the population from previous year. The Alaskan catch, now less than one-fourth of the national total, could expand substantially with further developments (5). One writer predicted that the Alaskan stocks are capable of producing a catch equal to or exceeding 250 million pounds annually, or 5 times the existing Alaskan catches (38).

Jensen (21) estimated that 78 to 85 percent of the shrimp is wasted in mechanical peeling and 77 to 85 percent in hand picking. The Oregon State Department of Environmental Quality (17) estimated 78 percent for hand picking and the Bureau of Commercial Fisheries listed a cleaning loss of 55 percent (22). The low value from the Bureau of Commercial Fisheries was apparently due to ignoring the blanching loss, which ranges from 30 to 35 percent of the picked wastes (26). Using a value of 80 percent wastage, the quantity of shrimp wastes generated in 1968 was calculated to be 233 million pounds.

Shrimp waste has been analyzed and been shown to be predominantly protein, chitin (a complex polysaccharide, not readily biodegradable) and calcium carbonate, as outlined on Table 4.

Table 4. Composition of Shrimp Wastes (29)

Source	Composition		
	Protein (%)	Chitin (%)	Calcium Carbonate (%)
Hand picking	27.2	57.5	15.3
Mechanical picking	22.0	42.3	35.7

The protein concentration in shrimp waste has been judged satisfactory for animal feed (30). Crawford (31) reported that mechanical shrimp peeler effluents sampled averaged 29,000 mg/l total solids.

CRAB

The blue crab, comprising 70 percent of the U.S. crab production, is harvested on the Atlantic Coast, principally in the Chesapeake Bay area. The remaining harvest takes place on the Pacific Coast where Dungeness crab is the leading species followed by Alaskan king crab. Crabs are harvested from shallow water in baited traps. Rapid and careful handling is necessary to keep the animals alive. Dead crabs must be discarded because of rapid decomposition.

At most canning plants, the whole crabs are steam-cooked in retorts for 20 to 30 minutes (32). Pacific Coast Dungeness crab operations differ in that they first butcher the crabs (i.e., remove the backs) and then cook the crabs for 12 minutes or less. Cooked crabs are also marketed in the shell, butchered, or the meats picked from the shell are marketed fresh, frozen, or canned. The majority of the Atlantic blue crab meat is marketed fresh or frozen, while the majority of the Pacific crab meat is canned (33). A large quantity of Dungeness crab is sold in the shell and a large quantity of king crab is butchered at sea (34). Both practices reduce the quantity of butchering waste to be handled at the processing plant site.

Figure 6 depicts a frozen crab operation. Crab canning and crab freezing operations are understandably similar. After cooking, the crabs are water-cooled to facilitate handling. The backs are removed, if they haven't been previously, and the remaining viscera are washed free. The cooking, cooling, and washing waters contain considerable solids and organic pollutants. After cooling, the meat is picked from the shell by hand with a small knife. Mechanical methods have been recently developed to extract the meat from the shell but are not as yet widely employed (35).

Crab meat quickly degrades in quality and must be chilled, frozen, or canned. Chilled meat can be stored for only a few days and even frozen meat looses texture and flavor qualities rapidly. Canning of crab meat results in the additional wastewater flows of the retort and cooling waters.

The total crab catch in 1968 exceeded [illegible] million pounds (5). The catches of the three main species seem to have reached a plateau. Production appears to be determined by the extent of previous years' hatches and the extent of harvesting rather than by marketing conditions. Future harvests of most species should continue at levels dependent on survival of offspring in the fishing grounds. Production of Alaskan king crab may eventually increase slightly due to stricter controls being imposed by the Alaskan Board of Fish and Game (5). The controls established a king crab fishing season from 5 to 7 months long in Alaskan waters. In 1969 all areas were closed on February 15 and not reopened until August.

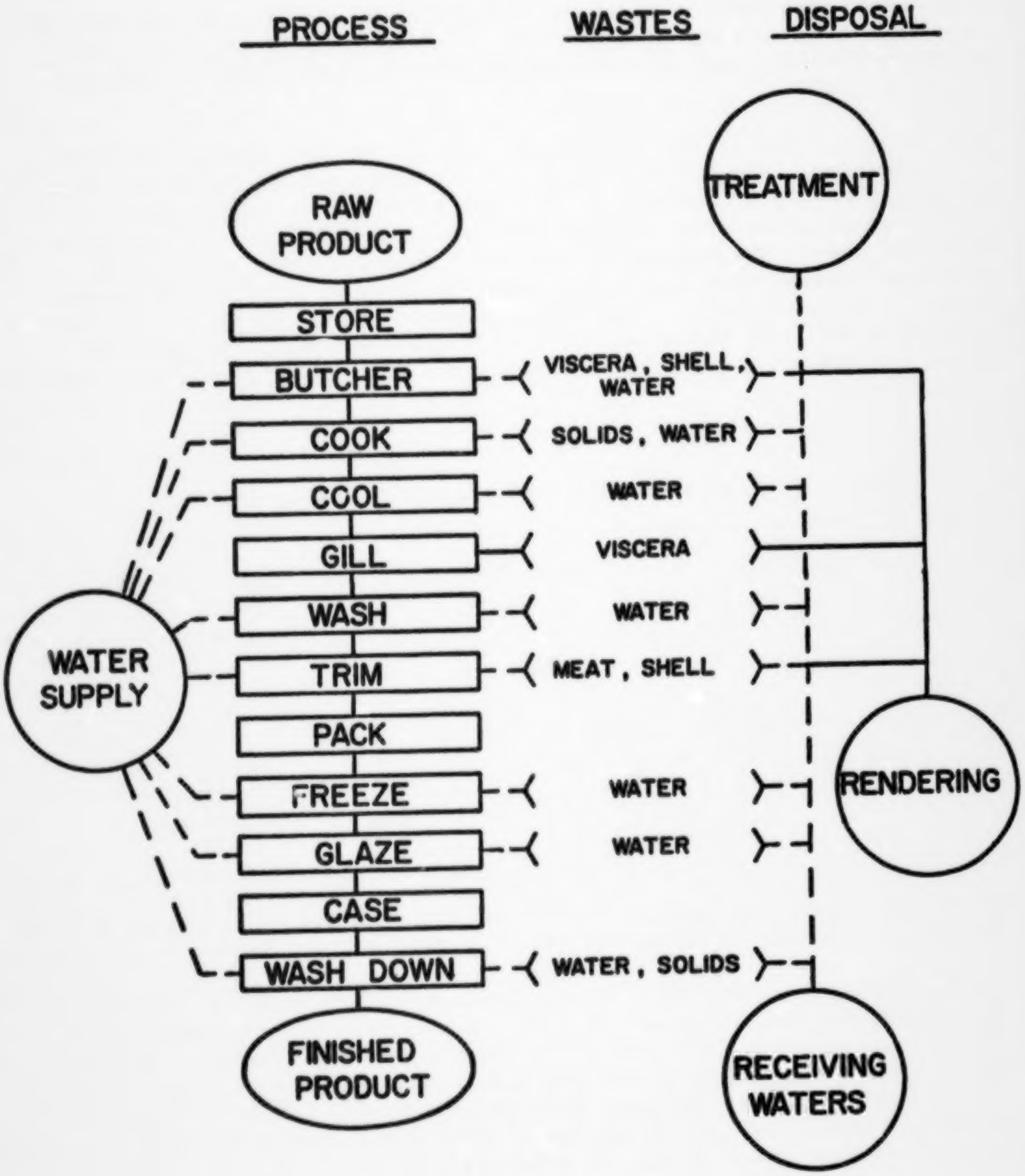
PROCESS
WASTES
DISPOSAL
RAW PRODUCT
STORE
BUTCHER
COOK
COOL
GILL
WASH
TRIM
PACK
FREEZE
GLAZE
CASE
WASH DOWN
FINISHED PRODUCT
WATER SUPPLY
VISCERA, SHELL, WATER
SOLIDS, WATER
WATER
VISCERA
WATER
MEAT, SHELL
WATER
WATER
WATER, SOLIDS
TREATMENT
RENDERING
RECEIVING WATERS

FIGURE 6 CRAB FREEZING

The tanner crab harvest has been increasing in recent years due to the decreased availability of king crab. Abundant stocks exist off the Northern Pacific Coast and harvesting of this species should rapidly increase (28).

The major portion of the crab is not edible and as a result is wasted in processing. The waste consists of the shell and entrails and amounts to approximately 80 percent of the crab by weight. Large quantities of water are necessary for cooking, cooling, and washing of the entrails from the body. The wastage of the total crab has been reported as: blue crab, 86 percent (32); king crab, 80 percent (21); and Dungeness crab, 73 percent (22). Using these figures, the solid waste load for crabs for 1968 was calculated to be 194 million pounds, as shown on Table 5. The actual wastes volumes at the processing plants were less, because a significant proportion of the crabs harvested (especially Dungeness) are marketed whole or butchered whole to remove only the backs and entrails.

Table 5. Calculated Quantities of Crab Waste, 1968

Species	Waste Fraction (%)	Waste Quantity (lbs x 10^6)
Blue	86	94
Dungeness	73	32
King	80	68
Total		194

The composition of shellfish wastes is largely determined by the exoskeleton. The exoskeleton is composed primarily of chitin, protein bound to the chitin, and calcium carbonate. The major portion of the wastes consists of exoskeleton materials with varying significant amounts of attached or unrecovered flesh and visceral material included. The Ketchikan Technological Laboratory of the Bureau of Commercial Fisheries reported typical compositions of these wastes as shown on Table 6.

Table 6. Typical Crab Waste Compositions (29)

Species	Sources	Protein (%)	Chitin (%)	Calcium Carbonate (%)
		Composition		
King	Picking line	22.7	42.5	34.8
Tanner	Leg and claw shelling	10.7	31.4	57.9
Tanner	Body butchering and shelling	21.2	30.0	48.8

The protein level is considered low compared to visceral fish wastes, thus, this material is considered only marginally satisfactory as an animal feed.

Crab processing wastes, like shrimp, include large volumes of processing washwaters, solid wastes, canning waters (where applicable) and plant clean-up water. No information was found in the literature describing the organic strengths and liquid waste volumes from shellfish processing, although currently on-going research may fill this void.

BOTTOM FISH

The most important bottom fish species are listed by Slavin and Peters (36) as haddock, halibut, cod, ocean perch, whiting (silver hake), flounder, hake, and pollock. Approximately 30 percent of the industry is located in the North Atlantic region. The major halibut fishery is centered in the Pacific Northwest where the commercial season extends from April through October.

Bottom fish are usually caught in otter trawls. In a typical operation, the fish are spread on the trawler decks, sorted and iced. Perch, flounder and whiting are stored whole, whereas cod, haddock, halibut and pollock are usually eviscerated on deck. The viscera and blood are washed overboard.

Bottom fish are normally filleted. The typical filleting operation is depicted on Figure 7. After unloading, the fish are weighed, washed, and iced in tote boxes. In some larger plants, mechanized unloading methods are used to maintain quality. In small plants, the fish are processed by hand. The fillets are cut on a wooden board next to a sink, washed and immediately iced in boxes for distribution.

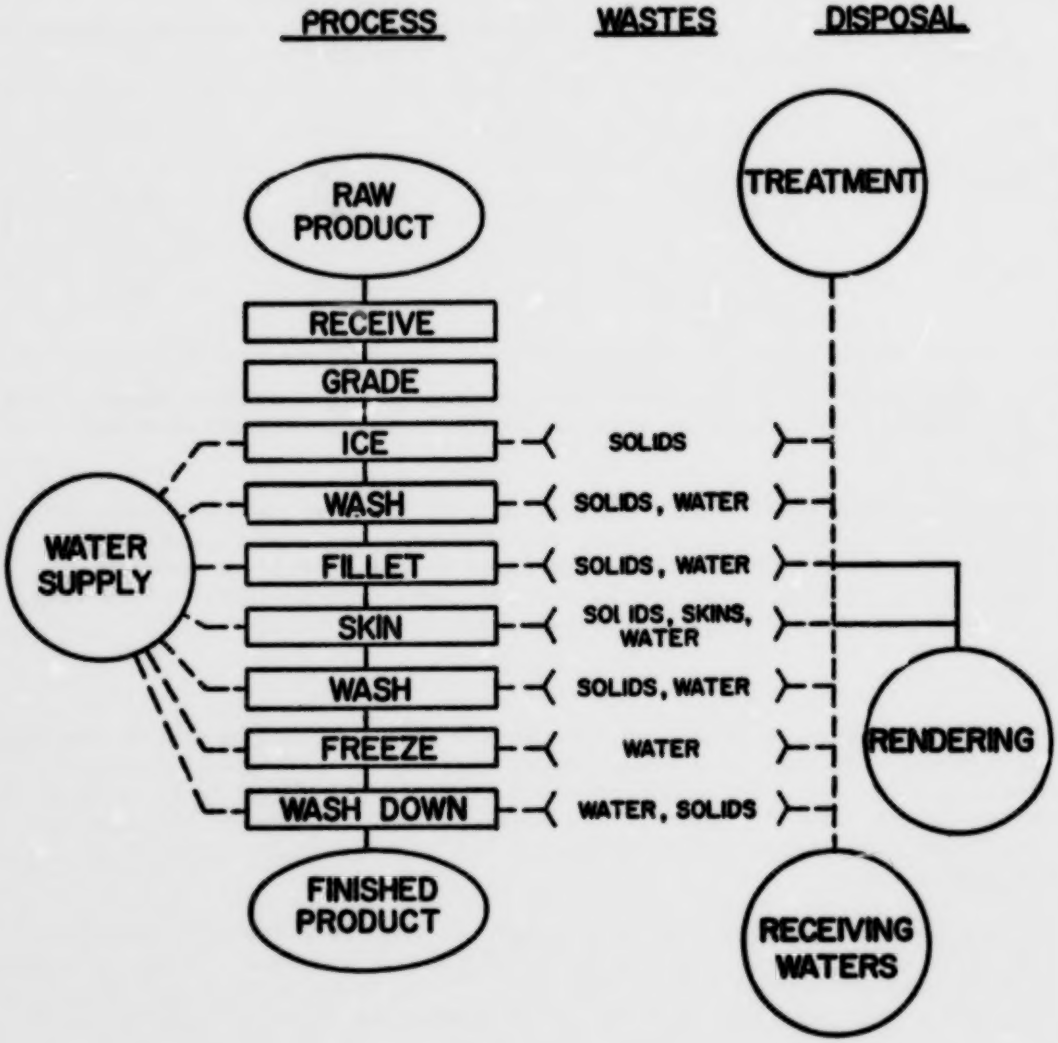
PROCESS
WASTES
DISPOSAL
RAW PRODUCT
RECEIVE
GRADE
ICE
WASH
FILLET
SKIN
WASH
FREEZE
WASH DOWN
FINISHED PRODUCT
WATER SUPPLY
SOLIDS
SOLIDS, WATER
SOLIDS, WATER
SOLIDS, SKINS, WATER
SOLIDS, WATER
WATER
WATER, SOLIDS
TREATMENT
RENDERING
RECEIVING WATERS

FIGURE 7 BOTTOM FISH FILLETING

Most plants processing fillets use mechanized equipment. First, the fish are washed with sprays of water in large rotating tumblers; then they pass through filleting machines or along hand filleting tables. Filleting machines only operate on certain sizes and shapes, but they are considerably more efficient and economical than hand filleting. The skin is removed from the fillet by hand or machine. The solid wastes from filleting and skinning operations are usually rendered for pet food or animal meal.

The skinned fillets are transported by a conveyor belt to a washing and at times a brining tank. After inspection, the fillets are packed in containers or frozen and then packed. Fillets are marketed frozen (fresh or breaded), chilled, or fresh.

In 1968 the bottom fish catch exceeded 490 million pounds, of which approximately 190 million pounds was harvested on the Atlantic Coast (5). The total domestic supply of bottom fish fillets and steaks has been steadily declining since the 1940's (5). The major reason for the drop in domestic production seems to have been lower yields in Atlantic Coast waters. The halibut production, on the other hand, has been predicted to remain, in the near future, at approximately the 1968 level of 26 million pounds (21). This estimate was based on consumer demand, requirements for growth and limits imposed by the International Pacific Halibut Commission.

About 35 to 40 percent of the halibut is wasted in processing (21). The viscera are usually disposed of at sea. The remaining wastes (heads, skins and fins) have been estimated to amount to approximately 12 percent of the total wastes (37). Using this 12 percent figure, the halibut wastes in 1968 were calculated to total 3 million pounds. In most other filleting operations, the fish are not eviscerated. The unfilleted portions are discarded or recovered for by-products. Water is run continuously in the spray-washers and during filleting and skinning for bacteriological control. Blood and small pieces of fish flesh are entrapped in this flow. Other waste flows include the packing ice and the cooling waters.

The Oregon State Department of Environmental Quality estimated the solid waste fraction from bottom fish processing to range from 35 to 40 percent (17). Using the 40 percent value, the total waste quantity for bottom fish in 1968 was calculated to be 189 million pounds. As noted earlier, cod, haddock and pollock are eviscerated as caught and the wastes dumped at sea. This decreased the estimate of total processing plant wastes to 139 million pounds per year.

Thurston (38) determined the composition of wastes from sole and flounder processing. Composite samples were prepared from the non-edible parts of 214 fish. The average composition was: moisture, 77.4 percent; oil, 5.68 percent; protein, 13.6 percent; ash, 3.84 percent; sodium, 0.16 percent; and potassium, 0.22 percent. Although the non-edible parts of sole and flounder had lower values for protein and ash than did those of other saltwater species, they were judged to be of high enough quality for by-product utilization. The fish averaged 72 percent waste. The waste flows from bottom fish processing plants include large volumes of wastewater which contains blood, small pieces of flesh, the body portion of the fish after filleting and the skin. Claggett and Wong (11) measured the waste flow from a bottom fish plant to be 450 gpm, with a solids loading of 750 mg/l. Other investigators (24) have reported organic loadings varying from 192 to 640 mg/l BOD_5 with the average being 74 pounds of BOD_5 per ton of fish. Reported bottom fish processing wastewater characteristics are summarized on Table 7.

Table 7. Bottom Fish Processing Wastewater Characteristics

Flow (gpm)	BOD_5 (mg/l)	Suspended Solids (mg/l)	Reference
105	640	300	(25)
320-410	192-640	---	(24)
132	1726	---	(39)
450	---	750	(11)

BY-PRODUCT UTILIZATION

Much effort has been devoted to the development of saleable by-products from seafood processing wastes. From a standpoint of water pollution abatement, however, only one by-product group has contributed significantly to reducing the magnitude of the problem: fish meal and other animal feeds. The other processes (discussed later) consume only a small portion of the wastes and new wastes generated in the processes often are more noxious and less biodegradable than the original waste. If any of these methods were developed into profitable enterprises, however, the revenues realized from these operations could conceivably be used to partially defray the expense of disposing of the remaining wastes.

The use of whole fish and fish scraps for animal feed has been studied thoroughly. The fresh wastes or whole fish are usually processed to a fish meal, fish oil or animal feed (cooked and canned). In addition to meal and oil plants, there were in the United States in 1968 ten plants processing crushed shell for poultry feed, four plants producing animal feeds and two plants producing pelletized fish hatchery feed, all from fish wastes and whole fish (40). Jones (41) discussed the various species and their wastes that could be used for pet food for several geographic areas of the United States. He concluded that now-discarded fish and fish wastes will be needed in the future to satisfy increased raw material demands. Several species of under-utilized fishes were listed. However, if all amenable wastes were processed into fish meal or other animal feed at this time, it is questionable whether the market could absorb the increased supply.

Besides fish meal, oils, solubles, and other animal feeds, many products based on fish wastes have been developed and/or promoted in the past. These include protein hydrolysates, fats and lipids, enzymes, homones, vitamins, chitin, glucosamine, fertilizers, lime, limestone, pearl essence, glue, caviar and other roe products, shell products and fish protein concentrate. The processes resulting in these products in general fail to reduce significantly the magnitudes of the wastes from which they are made. In most cases, only a very small fraction of the waste is utilized and the remainder must still be handled.

STANDARD WASTE TREATMENT METHODS

The liquid wastes resulting from fish processing are most commonly discharged to the adjoining waters. This practice has been restricted in many areas recently because of the consolidation of plants and intensified enforcement of long-standing and new water pollution regulations. The alternative in many cases has been to discharge the wastes to the municipal sewerage systems. In only one instance did the literature describe a United States processor having on-site treatment of fish processing wastes before discharge to a water body (42).

The specific difficulties encountered in the treatment of fish processing wastes are, in large part, attributable to the characteristics of the wastes. These are usually: high flows, medium to high BOD_5 and suspended solids, and high grease and protein levels, compared to domestic sewage. The frequently short processing season, high peak loadings, and rapid biodegradability of the wastes also contribute to the problem.

Claggett and Wong (43) studied the effectiveness of screening the wastes. Two specific screen types were tested: rotary and tangential. A 34-mesh rotary screen made of stainless steel was first investigated. The 4 foot-long barrel section was rated at 100 gallons per minute. Solids were removed on a screw conveyor and blinding was prevented through the use of high pressure nozzles. The tangential screen employed two screening surfaces, each one square foot in area, sized at 20 and 40 mesh. The resulting operating capacities were 35 and 20 gallons per minute, respectively. Both screens were judged successful for salmon canning wastes (43). The results indicated that with the low investment and operating costs associated with screening, a processor could expect removals of over one-half of the total solids from his wastewaters.

Jaegers and Haschke (44) stated that centrifuges can be effectively used to remove fish pulp from the waste streams. Fats and proteins can also be recovered with this method. However, centrifuging entire waste streams would be very expensive when compared to other methods.

In the processing of oily fishes (sardines, herring, etc.), large quantities of fats and greases are present in the wastewaters. Knowlton (45) reported the fat and grease content of sardine canning wastewaters to be from 1,000 to 30,000 mg/l compared to 50 to 200 mg/l for domestic sewage. Fats and grease are present as flotables or as emulsions. When the wastes are discharged untreated, serious problems can result if the emulsified grease coalesces and rises to the surface of the receiving waters.

Grease can be removed in clarifiers by two methods: flotation and sedimentation. Limprich (39) reported that the application of 2.5 grams of clay, 2.5 grams of lime and 100 milligrams of ferric chloride per liter of waste gave an optimal precipitation with a resulting 75 percent decrease in BOD_5. A similar procedure was described by Schulz (46) using Al_2O_3, lime, and ferric chloride. Griffen (47) mentioned that high fat and protein wastes can be treated with lime. Chlorination before sedimentation was recommended to prevent the serious odor problems that can result from rapid degradation.

Sedimentation tests of fish processing wastewaters were reported by Buczowska and Dabaska (48). In two hours of quiescent settling, 32 percent of the suspended solids were removed with a concomitant BOD_5 removal of 25 percent. About 58 percent of the organic matter in the wastewaters was in solution or colloidal suspension. Limprich (39) stated that 58 percent of the suspended matter in fish wastes settled out in two hours. Large volumes of sludge resulted.

A partially successful gravity clarification system was developed using large quantities of a commercial coagulant called F-Flok (43). F-Flok is marketed by the Georgia-Pacific Corporation and is derived from lignosulfonic acid. The floc formed slowly, but after formation sedimentation rates of 4 feet per hour could be achieved. The summary for a large scale test on salmon wastewater (Table 8) shows a maximum solids removal of about 70 percent.

Table 8. Gravity Clarification Using F-Flok Coagulant (43)

Coagulant Concentration (mg/l)	Total Solids Recovery (%)	Protein Recovery (%)
5020	68	92
4710	60	80
2390	47	69

An alternative to the normal sedimentation clarifier is the flotation cell. The flotation technique relies on the entrainment of minute air bubbles which float particles to the water surface. The resulting sludge blanket is continuously skimmed from the surface. Two methods are used to entrain the air bubbles in the flow, each method having advantages over the other. The first method uses mechanical aerators to "whip" air bubbles into solution. Dreosti (49) reported that good laboratory results were obtained using fish wastes with suspended solids levels up to 8,000 mg/l. Higher suspended solids concentrations produced sludges that did not consolidate well on the surface. For optimum results, Dreosti recommended a minimum of air flotation and short agitation times. Coagulants improved the removal efficiency; however, no mention was made of types or quantities used. The minimum detention time was estimated to be five minutes. Hopkins and Einarsson (42) reported on the results of a similar flotation unit operating on fish wastes at a flow of 0.065 mgd. The resulting sludge contained 15.5 pounds of grease and 35 pounds of fish solids per day.

The second flotation method involves flow pressurization. The total flow or a part of the flow is pressurized and then passed into the flotation unit which is at ambient pressure. The now supersaturated solution begins to release air, forming many tiny bubbles. These bubbles then float the suspended solids to the surface. This method requires pressure pumps and containers and necessitates the recirculation of a portion of the flow, however, greater efficiency is usually obtained than with the "whipping" method. Three papers (11, 43, 50) describe in detail pilot-scale tests of the flow pressurization method of flotation clarification of fish processing wastes. Water was pressurized by a centrifugal pump at about 40 psig. Air was added at the rate of about 2 percent by volume. The pressurization tank had a one-minute detention time. The recovered sludge was heated and then the protein and oil fractions were removed by centrifugation. All tests were conducted using coagulant aids. The specific aids tested were alum, ferric chloride, F-Flok, aluminum hydroxide, Zetol-A (trade name for an animal glue), and lime. In the first tests on salmon processing wastewaters, alum, ferric chloride, and F-Flok were compared. Alum and ferric chloride performed well as coagulants but large doses of F-Flok were necessary to achieve comparable results. The iron in the ferric chloride tended, however, to catalyze lipid oxidation and this coagulant aid was thus judged unsatisfactory. Further tests were conducted and the authors concluded that flotation cells could be used effectively on fish processing wastes. Alum treatment was judged the most promising of the methods used. Feeding tests showed that alum could be included in the recovered solids up to the 1 percent level and the resultant sludge fed to chickens without altering their growth rate.

A method has been developed (51) to remove fish oils down to the 0.008 percent level by acidifying the waste stream followed by flotation. This method requires neutralization after treatment. Specially-coated treatment equipment is needed to reduce corrosion.

Little work has been done on biological treatment of seafoods processing wastes. Buczowska and Dabaska (48) did report that the carbon-to-nitrogen ratio of fish processing wastewaters is satisfactory for biological treatment. The biochemical oxidation rate was said to be similar to sewage, but nitrification begins sooner and is more significant. Assuming primary stage removal of reasonable levels of solids, greases and oils, the authors concluded that no special treatment problems should be encountered. Without this pretreatment, several problems can develop. For example, the oil and grease can interfere with oxygen transfer in an activated sludge system (52). Czapik (53) reported on a trickling filter that clogged due to high levels of solids and oil from a fish processing plant.

Anaerobic treatment of fish wastes has been investigated (9). Liquid fish wastes were judged to produce no unusual problems in a digester operation when in-plant screening was employed. Matucky, et al. (52) stated that fish solids and oils digested readily and the resultant sludge dewatered easily. The digester loading rates used by these investigators varied from 0.1 to 0.35 pounds of volatile solids per cubic foot per day.

CURRENT RESEARCH

A variety of research projects on subjects relating to fish processing wastes are presently in progress or recently completed. These projects are briefly summarized below to describe the general trends in research efforts and to indicate specific individuals who can provide up-to-date information.

Harvesting and Processing Modifications

The Oregon State University Seafoods Laboratory (54) is presently studying the efficiency of the Yanagiya Flesh Separator. The device consists of a revolving stainless steel drum perforated with numerous 1/16" diameter holes. A continuous belt is held against a portion of the drum. Whole fish or filleted fish bodies are placed between the revolving drum and the belt and the soft flesh portions are continuously pressed through the drum and thereby extracted. Present data show excellent recovery of the flesh portions from the bone structures of the fish. A larger model of this device is presently being used by one Oregon processor to remove cooked tuna flesh from bone scraps. The recovered flesh is processed as dog and cat food.

Richardson and Amundson (55) have undertaken a 5-year study of rendering processing of Great Lake alewives. Microbial activity is used to separate the oil and scrap. Proposed uses are fish protein concentrates, fish oils and various oil-based products.

The College of Fisheries of the University of Washington (56) has concluded research on the enzyme digestion of shrimp wastes. An effort was made to develop an active digestive system that could operate at high temperatures.

Law (57) currently has a U.S.D.A. grant to study the utilization of marine waste products.

A new rapid method of ship-board fish meal production has been developed by a Mexican firm (58). Fresh fish are ground and dried simultaneously in a 240°C gas stream. The meal is then cooled and packaged. The complete process takes from 6 to 8 seconds as compared to 22 minutes in an alcohol extraction process. One ton of fish meal is recovered from five tons of fish. No reference was made to the applicability of this method to fish wastes, but there is no obvious reason to discount it as a possibility.

A packaged on-board freezer has been recently marketed by a Pennsylvania firm (59). This unit freezes up to 300 pounds of shrimp per hour and maintains freezing temperatures in the storage hold. Utilization of this apparatus could eliminate the use of ice and its resultant wastewater.

Two new American ocean vessels have recently been active in the harvesting and processing of fishery products (60). Named the Seafreeze Atlantic and the Seafreeze Pacific, these two ships cost over $5 million each, and each can handle 50 tons of fish per day. Processing is so complete that "only the skins are wasted". If this venture proves successful, terrestrial accumulation of fish processing wastes could be substantially reduced in the future.

The Bureau of Commercial Fisheries (61) has developed a trap to harvest the sablefish population off the Pacific Coast. The trap has been judged to be moderately successful and further development is planned.

Waste Strengths and Volumes

The National Canners Association (62) is presently conducting research on wastewater characteristics from sardines, shrimp, salmon, and tuna processing plants. The wastewater parameters to be measured are COD, BOD_5, total solids, dissolved solids, suspended solids, oil, grease, nitrogen and chlorides. A study on Maine sardine plants has been completed.

Waste Treatment

A Northern California firm (30) has developed a direct-fired gas drier to economically dry fish meal. The drier jet exhausts upward with an adequate velocity to "fluidize" the drying bed of meal. High heat efficiencies have been obtained with this machine (i.e., greater than 95 percent recovery).

Kempe (63) has proposed research on the efficiency of spray-evaporation of stickwater. This method is considered to be superior to other evaporation methods due to lower cost, simplicity of operation, and faster start-up. These factors are especially important to the smaller rendering plants with limited capital.

Johnson and Hayes (64) have proposed a pilot plant study of the utilization of the chitin fraction of king crab wastes. Matthews (64), of the University of Alaska, is presently studying the utilization of king crab wastes.

Deyoe (65), at Kansas State University, has proposed research on the nutritive value and economic utilization of catfish processing wastes. Meals produced by various methods would be chemically analysed and animal feeding tests performed.

RECOMMENDATIONS FOR FURTHER RESEARCH

Factors Influencing Research Recommendations

The survey of the seafood industry demonstrated that the water pollution problems generated therein are, with a few isolated exceptions, not as critical as those of many other industries. There are two basic reasons for this conclusion. First, seafood processing plants generally dispose of their wastes into estuaries, which results in dispersion and dilution. Soluble pollutant loads are quickly reduced in well-mixed estuarine environments. Secondly, in many cases the processing plants are located in sparsely populated areas where other industrial wastes and domestic wastes are of limited magnitudes, minimizing the competition for the assimilative capacities of the estuaries. This is not to say that seafoods processing pollution problems can be justifiably ignored; rather that it is advisable to attack the problems systematically and develop reasonable solutions in a rational manner.

In the opinion of the authors, based on personal experience and the consensus expressed in the literature, seafoods wastewaters are readily amenable to biological treatment and should present no special difficulties from the standpoint of toxicity. The problem with the wastewaters, therefore, remains basically one of economics, not of technology.

Economics also seems to be the major concern in the disposal of solid wastes. Solid wastes, unlike liquid wastes, are of potentially significant economic value in the form of by-products. This potential should be recognized and utilized wherever possible in future research and development efforts.

The seafoods industry consists of a myriad of processing centers located along our coastlines. The plants are frequently autonomous, intensely competitive, and notably lacking in cooperative spirit. Common problems are seldom handled jointly. Organizations such as the National Canners Association, National Fisheries Institute, Pacific Fisheries Technologists and others are striving to reverse this trend, but without much success to date. One outstanding exception to this pattern is the current cooperative effort being mounted by the crab processors of Kodiak, Alaska. This undertaking involves the common collection of solid wastes followed by disposal at a single sanitary landfill. Hopefully, this activity is indicative of a developing awareness within the industry of the advantages of attacking in concert the water pollution problems common to all.

The lack of geographic concentration of the industry will tend to influence the type of research undertaken. Solutions which rely on combining the effluents (or solid wastes) from several plants or, the effluent from a single plant with that of a sizeable municipality, will not always be appropriate. Many of the major offenders are remotely located, with few, if any, other industries near at hand, and with only a handful of nearby residents who are most likely employed by the cannery. This situation, of course, is not usually the case, but, nonetheless, is common enough to warrant consideration.

The diversity of the industry is an added factor which must be considered when planning waste utilization and treatment research. Unlike some of the single-commodity food processing industries, the seafoods processors produce wastes which, while all highly organic and nitrogen-rich (excluding cooling waters), vary from negligible to staggering volumes.

Funding alternatives, both for research and for the ultimate full-scale utilization of the research findings, are an especially important consideration in this case. The industry, as most of the food industries, is typically a low profit enterprise. This fact, compounded by the current stationary production posture and increasing pressures from foreign competitors has already forced many small plants to discontinue operation. Significant increases in expenses, whether for in-house research or water pollution control, are likely to be untenable to many of the remaining smaller processors. Public research and demonstration project funding and treatment facility subsidies (in the form of tax credits or similar arrangements) will probably be necessary to permit the industry to survive in its present form.

Recommendations

It appears that the most urgent research needs in the seafoods field lies in three main areas: (a) demonstration scale (solid and aqueous) waste treatment and/or disposal projects; (b) development of in-plant processing modifications (including by-product development) designed to reduce wastage; and (c) production-scale projects demonstrating the technical and economic feasibility of the solutions developed in (b).

To provide the bases for abating the most critical problems now facing a few plants, item (a) should be given highest priority. To make allowance for longer term considerations, items (b) and (c) should also be afforded increased emphasis. In many cases, the basic work outlined in item (b) has already been accomplished (or nearly so), and it only remains to demonstrate the new approach. Work with flesh separators, for instance, has indicated, at least in a preliminary fashion (54), that significant solids recoveries can be realized. Perhaps full-scale demonstration of this concept should be encouraged.

Similarly, the previously-mentioned high-speed shipboard meal plant (57) could be applied to fish waste utilization and its effectiveness evaluated.

Floating canneries are just now being placed into operation (59). Their advantages from the standpoint of wastes reduction should not be overlooked as their performances are studied.

Waste Treatment and Disposal

Before demonstration-scale projects can be intelligently developed the designer must be familiar with the characteristics of the wastewaters with which he is dealing. Definitive studies of seafoods processing wastes are scarce, especially for shrimp and crab processing. Further work in this area should be supported.

Most states' water quality standards are phrased in terms such as "....water quality shall not be impaired to the detriment of legitimate existing or foreseen water uses...." Since a treatment facility design is based on anticipated efficiencies (in terms of BOD_5 and suspended solids), the level of treatment must be pre-defined. This requires a thorough knowledge of the effects of the wastes on the aquatic environment, therefore, studies of the effects of seafood plant wastes on marine and estuarine environments should be conducted. In-depth investigations of dissolved oxygen depletion, temperature effects, benthic disturbances, tidal effects, effects on primary and secondary productivity, effects of highly variable and shock loadings, degree of and rate of off-season recovery and many other variables should also be conducted.

The applicability of standard treatment methods is generally well accepted, but has not been sufficiently demonstrated; nor have the optimum operational characteristics been defined for each major type of primary and secondary process. This should be done at full (demonstration) scale for sedimentation, flotation, biological filtration, perhaps activated sludge and ultimately aerobic and anaerobic digestion.

Joint municipal-industrial waste treatment should be utilized whenever practical, since the same advantages inherent in joint treatment of other industrial wastes also apply here: dilution, equilization, the economics of size, etc.

Innovative techniques and new treatment methods, while not critical to the immediate solution of the problem, should, nonetheless, be encouraged.

It is the opinion of the authors that solid waste should be considered a resource rather than useless refuse. Direct disposal, either in a landfill or at sea, should only be considered as a last resort, but in instances where deep sea disposal is the only acceptable alternative, perhaps investigations of methods, economics and consequences of deep sea disposal should be carried out.

Another alternative is to avoid concentrating the waste at the plant; i.e., pre-process at sea. Placement of an "iron chink" in a "mother-ship" which would accompany the salmon fishing fleet is one example. The wastes would be returned immediately to the fishing grounds. The effects of this practice would, of course, require attention.

By-Product Development

The manufacture of by-products from solid residues has been extensively researched, especially with regard to salmon. An evaluation of these methods as potential waste reduction techniques leads to the conclusion that only those which utilize all or most of the solids are helpful. Animal feeding and other whole-waste utilization methods should be stressed.

Perhaps more basic by-product development work is needed in the crab and shrimp industries, but, in general, the economic aspects of the operations should be emphasized. Market surveys are needed and transportation alternatives evaluated to determine the economic feasibilities of various approaches.

The seafoods industry has a problem: water pollution. It has not generally reached crisis proportions yet. It does, however, require immediate, but rational attention. The various avenues of approach should be investigated for each general geographical area and each commodity subsection and the best combination of solutions delineated and implemented in each instance.

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CANNERY WASTE TREATMENT BY A HIGH SOLIDS ACTIVATED SLUDGE PROCESS

by

Warren G. Palmer*

INTRODUCTION

The activated sludge process is used for treating a variety of industrial wastes; however, these wastes often cause problems because of the seasonal nature of their shock loading effect on a conventional treatment plant by way of sudden high strengths or flows. Examples of such wastes are cannery, meat packing or processing, dairy, paper mill, and textile plant effluents. Adequate processing is needed to overcome such treatment difficulties.

An adaptation of the activated sludge process that appears to be capable of processing high strength wastes has been studied in Europe and uses high concentrations of mixed liquor suspended solids with little sludge wasting. This adaptation, which was a parallel development to extended aeration, is the Totalklaranlage developed by Professor Dietrich Kehr of the Technishe Hochschule in Hanover, Germany (2) and consists of an activated sludge with a concentration of mixed liquor suspended solids of 10,000 and 14,000 mg/liter and an aeration time of 6 hours. Kehr has reported high removals of BOD_5, nitrogen, and phosphorus with a loading of about 94 pounds of $BOD_5/1000\ ft^3$ of aeration tank. The high solids concentration of the process when coupled with physical conditions capable of maintaining a proper environment comprises an inherent buffering capability for high strength waste.

The basic objectives of the investigation reported herein are to demonstrate reliable performance of an adaptation of the activated sludge process using high concentrations of mixed liquor solids. The FMC Corporation has termed this the "Kehr Activated Sludge Process" (KASP). This system is to treat both domestic sewage and cannery wastes having BOD_5 strengths of 200 to 2000 mg/liter.

This study was financed under the United States Department of the Interior FWPCA Research and Development Grant 12060 EZP. The work was performed at FMC Corporation's Central Engineering Laboratories (CEL) in Santa Clara, California.

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This report describes the tests conducted to determine the effectiveness of the KASP for treating domestic sewage and cannery wastes.

THEORY

The activated sludge type of treatment plant has been widely used for stabilizing organic materials in both industrial wastes and domestic sewage. The microorganisms present in activated sludge floc accomplish stabilization of the organic materials by the mechanism shown in Figure 1. As illustrated, the decomposable organic substrate is used as food by the microorganisms to derive new cell mass by synthesis and energy for their metabolic functions by oxidation of the organic substrate to CO_2 and water. As well as using sewage organic wastes for food, the microorganisms utilize the degradable portion of the cell mass that is released on death of the cell. However, a portion of the cell mass is resistant to biological attack and cannot be readily metabolized. The final products of complete biological stabilization are then CO_2, water, and non-biodegradable organic matter.

The growth of microorganisms during the batch stabilization of an organic waste can be characterized by four phases. First a "lag phase" occurs where the microorganism population adjusts to the new environment. This is followed by the "log-growth phase" where there is sufficient food for unrestricted growth of the acclimated organisms. During this period of "log growth" the rate of BOD removal and cell growth is proportional to the number of organisms present. As the food concentration decreases it begins to limit the rates of cell growth and BOD removal. In this "declining growth phase" the rates of cell growth and BOD removal are proportional to the food present. Finally, "the endogenous phase" begins. In this phase there is insufficient food present to support cell growth at a rate greater than loss from death and lysing and active cell mass decreases. The degradable components of the lysing cells are metabolized by the remaining population.

Within an activated sludge system the organisms and waste present are quite heterogeneous causing these phases in actual operation systems to be the composite result of the reactions of the various organism populations with the food components. Most activated sludge systems operate in the "declining growth phase."

One mathematical model used to describe the rates of BOD removal and of sludge growth in the "declining growth phase" is as follows: (3)

$$\text{Sludge Growth Rate} = \frac{dm}{dt} = k_s F \qquad (1)$$

$$\text{BOD Removal Rate} = \frac{dF}{dt} = k_R F \qquad (2)$$

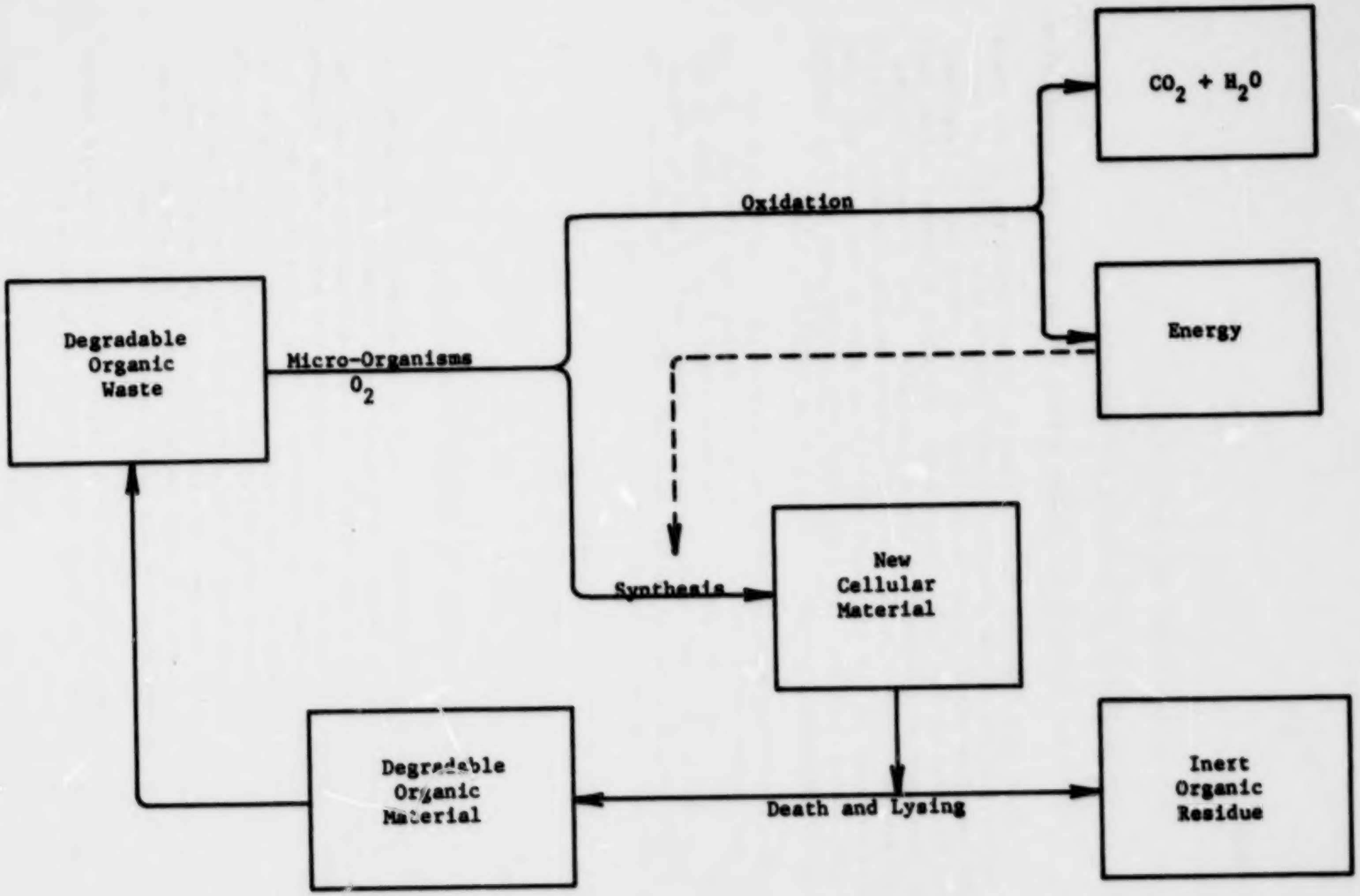

Degradable Organic Waste
Micro-Organisms
O_2
Oxidation
$CO_2 + H_2O$
Energy
Synthesis
New Cellular Material
Death and Lysing
Degradable Organic Material
Inert Organic Residue

Figure 1. MECHANISM OF MICROBIAL STABILIZATION OF AN ORGANIC WASTE

Where:

M = Active sludge mass concentration.

F = Total food or ultimate BOD concentration.

k_S = Rate constant for sludge growth in the declining growth phase.

k_R = Rate constant for BOD removal in the declining growth phase.

The active portion of the activated sludge floc is that portion of the sludge mass that enters into the dynamics of the system and it comprises only a fraction of the total sludge mass. Volatile suspended solids have often been used as a measure of the active mass. This procedure yields a much greater value than the real active mass because the 600°C ignition temperature used in the procedure volatilizes more of the total mass than just the active portion. For this report the active mass will be assumed to be some constant fraction of the volatile suspended solids.

The loss of cellular mass by endogenous respiration occurs during all the growth phases and is proportional to the active mass present. During the log-growth phase the loss by endogenous respiration is masked by the rapid growth and only during the declining growth and endogenous phases does endogenous respiration become important. The rate of cellular loss by endogenous respiration can be expressed mathematically as:

$$\frac{dM}{dt} = k_e M \qquad (3)$$

Where:

k_e = Rate constant for endogenous respiration.

The use of the previous equations to describe an activated sludge system is greatly simplified by using a completely mixed aeration tank. The contents of a completely mixed aeration tank are homogeneous so that the description of one portion of the tank describes the entire tank contents and the tank effluent. Smith (3) reported that all measurable BOD reduction in a completely mixed activated sludge plant takes place in the aeration tank. This further simplifies the use of the previous equations because it means that the composition of the solution phase of the plant effluent is essentially the same as that throughout the aeration tank. The total BOD of the plant effluent, being both solution and solid phase is affected by the efficiency of the solids separation process.

The solution phase BOD in effluent of a completely mixed activated sludge system operated in the "declining growth phase" is given as (3):

$$F = \frac{Fo}{k_R t+1} \qquad (4)$$

Where:

k_R = Rate constant for BOD removal in the declining growth phase.

F = Concentration of solution phase BOD in the effluent.

F_o = Concentration of BOD in the feed.

t = Aeration time of the sewage alone.

A material balance for active cellular mass can be made around an activated sludge plant. Such a balance sums cellular synthesis and cellular loss by endogenous respiration in the aeration tank as well as the amounts carried into and out of the system in the various liquid streams. Figure 2 shows a material balance for active cell mass around an activated sludge plant.

In a conventional activated sludge plant, part of the influent organic waste is disposed of as waste activated sludge solids which are composed of new cellular material and non-biodegradable matter. Because this waste activated sludge is difficult to handle, the extended aeration type of treatment plant was developed. Also known as the complete oxidation type of treatment plant, extended aeration attempts to obtain complete stabilization of the organic matter as illustrated in Figure 1.

Extended aeration produced aerobic digestion within the aeration tank rather than in a separate digester. Long aeration periods are used and the process attempts to operate such that the rate of synthesis of cellular material is equal to the loss by endogenous respiration. If the amount of cellular material flowing into and out of the treatment plant in the sewage and effluent are ignored, and no sludge is wasted, the material balance presented in Figure 2 can be rewritten as follows:

$$\frac{dMa}{dt} = k_s F - k_e Ma \qquad (5)$$

Where:

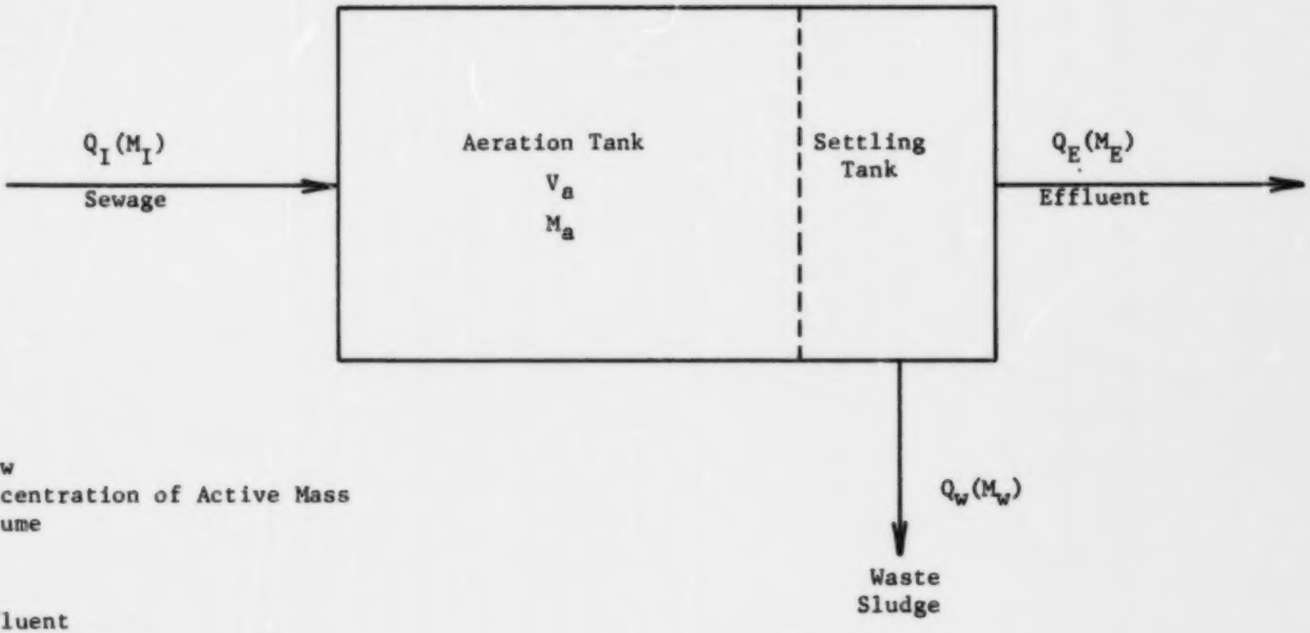
Ma = Concentration of active mass in aeration tank.

When extended aeration operates with no net cellular growth, $\frac{dMa}{dt}$ is equal to zero. For such a system equation 5 yields the following relationship of the concentration of active cellular mass to effluent BOD.

$$Ma = \frac{k_s}{k_e} F \qquad (6)$$

Accumulation = In - Out + Synthesis-Endogenous Loss

$$V_a \frac{dM_a}{dt} = Q_I M_I - (Q_E M_E + Q_W M_W) + k_s F V_a - k_e M_a V_a$$


$Q_I(M_I)$
Sewage
Aeration Tank
V_a
M_a
Settling Tank
$Q_E(M_E)$
Effluent
$Q_W(M_W)$
Waste Sludge

Symbols

Q = Flow
M = Concentration of Active Mass
V = Volume

Subscripts

I = Influent
a = Aeration Tank
E = Effluent
W = Waste Sludge

Figure 2. MATERIAL BALANCE FOR ACTIVE MASS AROUND AN ACTIVATED SLUDGE TREATMENT PLANT

Equation 6 shows that the steady state concentration of active mass is a function of the effluent BOD. Equation 6 may be combined with equation 4 to express the steady state active mass concentration in terms of the influent BOD and aeration time.

$$Ma = \frac{(k_s/k_e)\ Fo}{1+k_R t} \qquad (7)$$

Traditionally extended aeration plants have used long aeration periods resulting in low effluent BOD and a correspondingly low steady state active mass concentration. The KASP as practiced at FMC Corporation's Central Engineering Laboratories (CEL) operates on the principal of steady state concentration active mass but at shorter aeration periods with subsequently higher concentrations of effluent BOD and mixed liquor active mass. It was attempted to operate the system such that each aeration period at the existing sewage strength produced a steady state concentration of suspended solids in the aeration tank of about 10,000 mg/liter. Fluctuations in sewage strength prevented the aeration period to be matched exactly to the sewage so that the concentration of mixed liquor suspended solids varied from about 5,000 to 12,000 mg/liter.

As shown in Figure 1, the microbiological stabilization of the organic waste produces non-biodegradable sludge causing an increase in the total sludge mass. In any system such as the KASP with no intentional sludge wasting the production of the non-biodegradable solids will cause the sludge mass to increase to where the solids liquid separation systems capacity is overtaxed and solids will wash out in the effluent to prevent an unlimited increase in the mixed liquor solids. Both inert organic solids and active biological solids will be carried out in the effluent. Thus in a working system there will be uncontrolled wasting of active mass in the plant effluent, and the active mass in the mixed liquor will be less than that for true steady state operation.

TEST FACILITY AND EQUIPMENT

Permanent Facility - The permanent facility at FMC's Central Engineering Laboratories (CEL) Environmental Engineering site includes a 12" diameter inlet sewer from an 18" diameter sanitary sewer serving part of the City of Santa Clara. An adjustable hinged gate has been provided in the 18" line to divert sewage into the test site. A pumping station which receives the sewage from the 12" line is provided with two parallel open channels in which various forms of screening and comminution are available. Any one or all of the two channels and the 12" line may be closed off and emptied if desired. At the present time a standard Chicago Pump comminutor serves one channel and a production prototype Barminutor machine the other.

All sewage, whether directly from the sewer, screened, or comminuted, flows into a wet well located beneath the channels and comminuting equipment. In an adjacent dry well are two centrifugal pumps for delivering the sewage from the wet well through a six inch pressure line to an elevated flow splitter located in an outdoor test area. Valving in the dry well permits direct pumping back to the city sewer downstream from the point from which it was withdrawn. Maximum delivery to the elevated splitter is 750 gpm with both pumps running. A portion of the total flow to the splitter is diverted to a settling cone where grit and a portion of the suspended solids are removed. The overflow from this settling tank flows to another splitter box where it can be directed to sites throughout the test facility. A schematic diagram illustrating the CEL facilities is shown in Figure 3.

Experimental Facilities - A schematic drawing of the activated sludge system used for the KASP study is shown in Figure 4. The primary components of the system consisted of an aeration tank with a liquid volume of about 120 gallons and a circular sedimentation tank four feet in diameter.

Mixed liquor was pumped from the aeration tank to the final clarifier by a positive displacement pump driven by a variable speed motor. The flow rate was controlled by the speed of the motor. The return sludge was also pumped by a positive displacement pump and the flow rate was set equal to the settled sewage flow rate by a timer controlling the percentage of the time the pump was on. A float switch controlled the settled sewage flow.

A diurnal flow variation was produced by a 24-hour program timer, which controlled the power to the mixed liquor and return sludge pumps for each 5-minute interval during the day. A flow pattern similar to that at the San Jose - Santa Clara Water Pollution Control Plant could be produced by controlling the number of 5-minute cycles during each hour that the pumps were on and off.

Oxygen was supplied by a blower which pumped air through 4 carborundum diffusers 3 inches O. D. and 24 inches long. The air flow was varied from 16 CFM to 30 CFM to maintain the concentration of dissolved oxygen in the mixed liquor greater than 2 mg/liter.

A schematic flow diagram showing the arrangement of the experimental system is also presented in Figure 3.

EXPERIMENTAL PROCEDURE

Continuous operation of the KASP was performed by adjusting the flow rate of the return sludge to one half of the flow rate of mixed liquor to the final tank and the sewage flow, which was controlled by a float switch, made up the balance. Since no sludge was intentionally wasted, the only

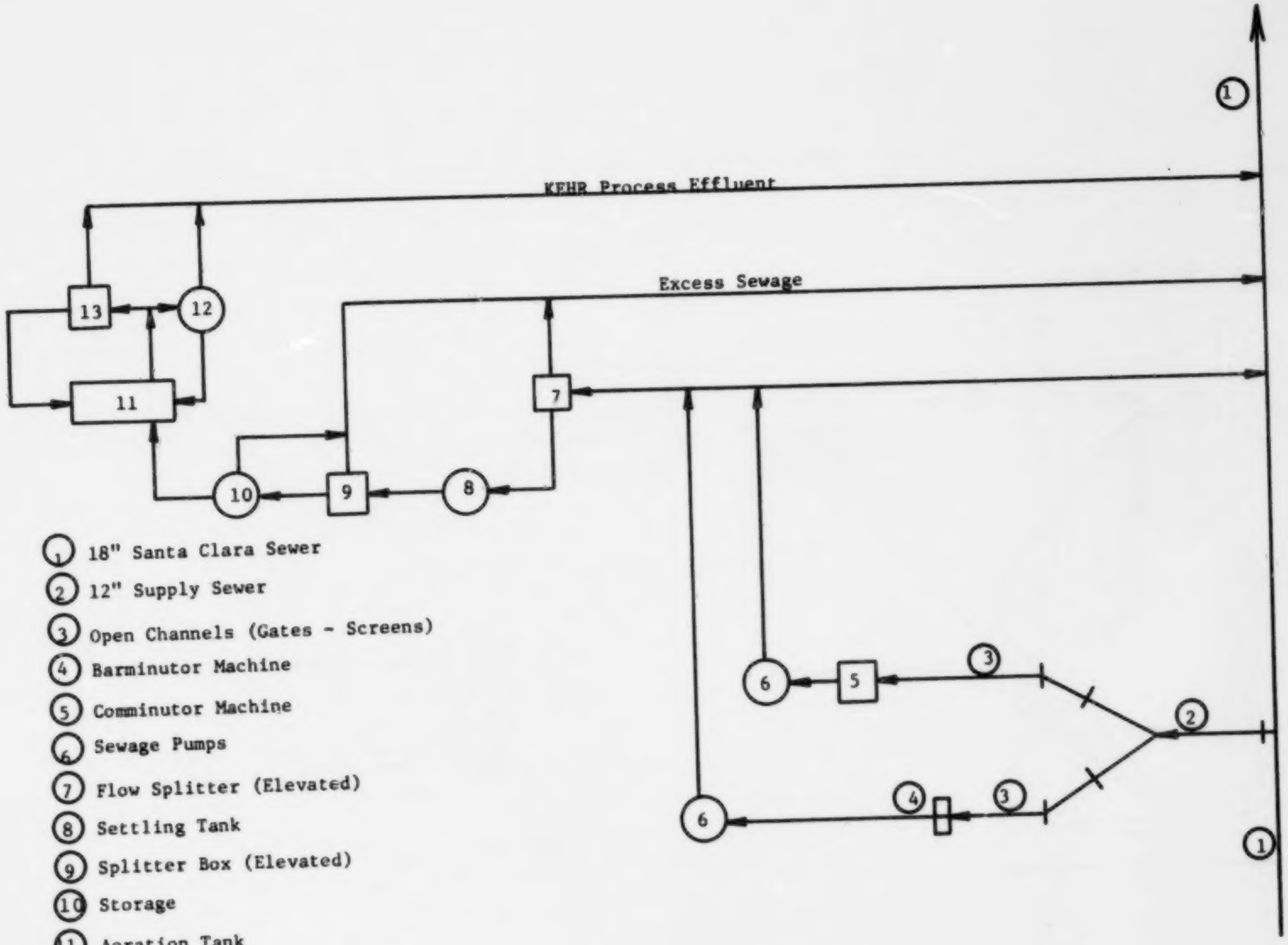

①
KEHR Process Effluent
Excess Sewage
13
12
11
7
10
9
8
6
5
③
6
②
④
③
①
① 18" Santa Clara Sewer
② 12" Supply Sewer
③ Open Channels (Gates - Screens)
④ Barminutor Machine
⑤ Comminutor Machine
⑥ Sewage Pumps
⑦ Flow Splitter (Elevated)
⑧ Settling Tank
⑨ Splitter Box (Elevated)
⑩ Storage
⑪ Aeration Tank
⑫ Final Tank
⑬ Electroflotation Cell

Figure 3. FLOW DIAGRAM, PERMANENT AND EXPERIMENTAL FACILITY

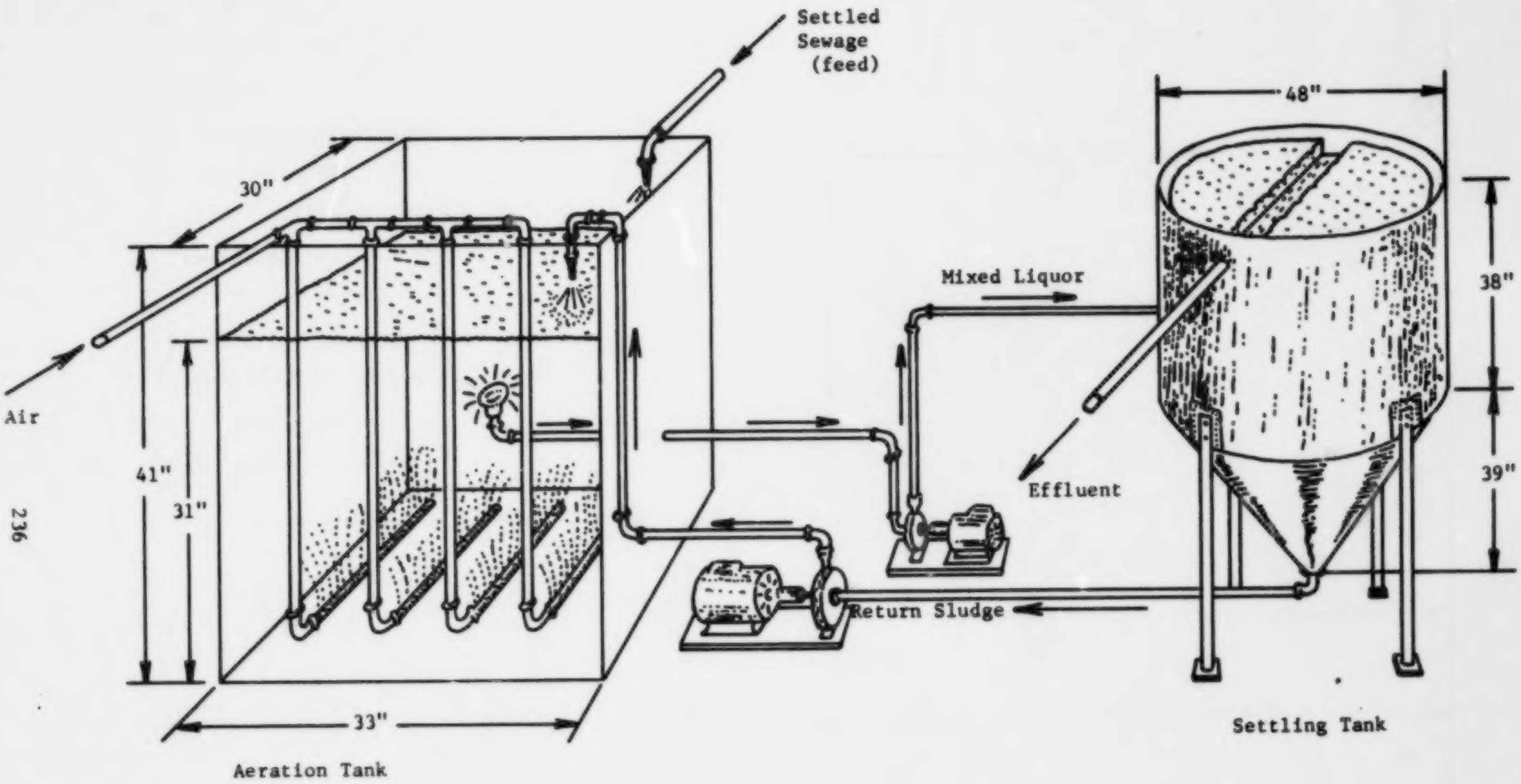

Settled
Sewage
(feed)
30"
Air
41"
31"
33"
Aeration Tank
Mixed Liquor
Return Sludge
Effluent
48"
38"
39"
Settling Tank

Figure 4. KEHR ACTIVATED SLUDGE PLANT

other control required was to maintain the flow of air in sufficient quantity to maintain the mixed liquor dissolved oxygen above 2 mg/liter. Both the sewage and effluent were sampled every hour during the 8:00 AM to 5:00 PM working day for an eight-hour composite. The mixed liquor and return sludge were sampled on a grab basis.

A programmed study was conducted to determine the performance of the high solids activated sludge system under shock loading conditions. This was designed to simulate shocking caused by a sudden decrease followed by a sudden increase in sewage strength. The underloading shock was simulated by changing the feed to the aeration tank from sewage to fresh water. After 48 hours the feed to the aeration tank was changed back to sewage so that an overloading shock occurred. The system was operated at a constant feed flow during this study. The constant feed was begun for one week prior to the test to insure that a steady state condition existed at the start of the test. Grab samples were taken of mixed liquor, return sludge, final effluent, and the sewage feed.

To determine if the KASP aeration tank was completely mixed, a tracer washout study was performed by first filling the KASP aeration tank with fresh water. Then a concentrated sodium chloride solution, simulating both sewage and return sludge, was pumped into the aeration tank. The effluent was periodically sampled and the concentration of the chloride was determined as a function of time. The course of the chloride concentration in the effluent from a completely mixed tank can be expressed mathematically by the following equation:

$$\log \frac{C_F - C_E}{C_F - C_I} = Dt \qquad (10)$$

Where: C_F = Feed concentration.

C_E = Effluent concentration.

C_I = Initial concentration in the system.

D = Tank displacement per unit time.

RESULTS

Tracer Washout - The degree of complete mixing of the aeration tank was determined by adding a sodium chloride solution (3400 mg/liter as Cl^-) to the aeration tank at a flow rate of 2.0 gpm, which resulted in a liquid detention time of 59 minutes. Effluent samples were analyzed for chloride and these data as well as the theoretical washout curve are plotted in Figure 5. The observed data points follow the theoretical curve very closely indicating that the aeration tank is completely mixed.

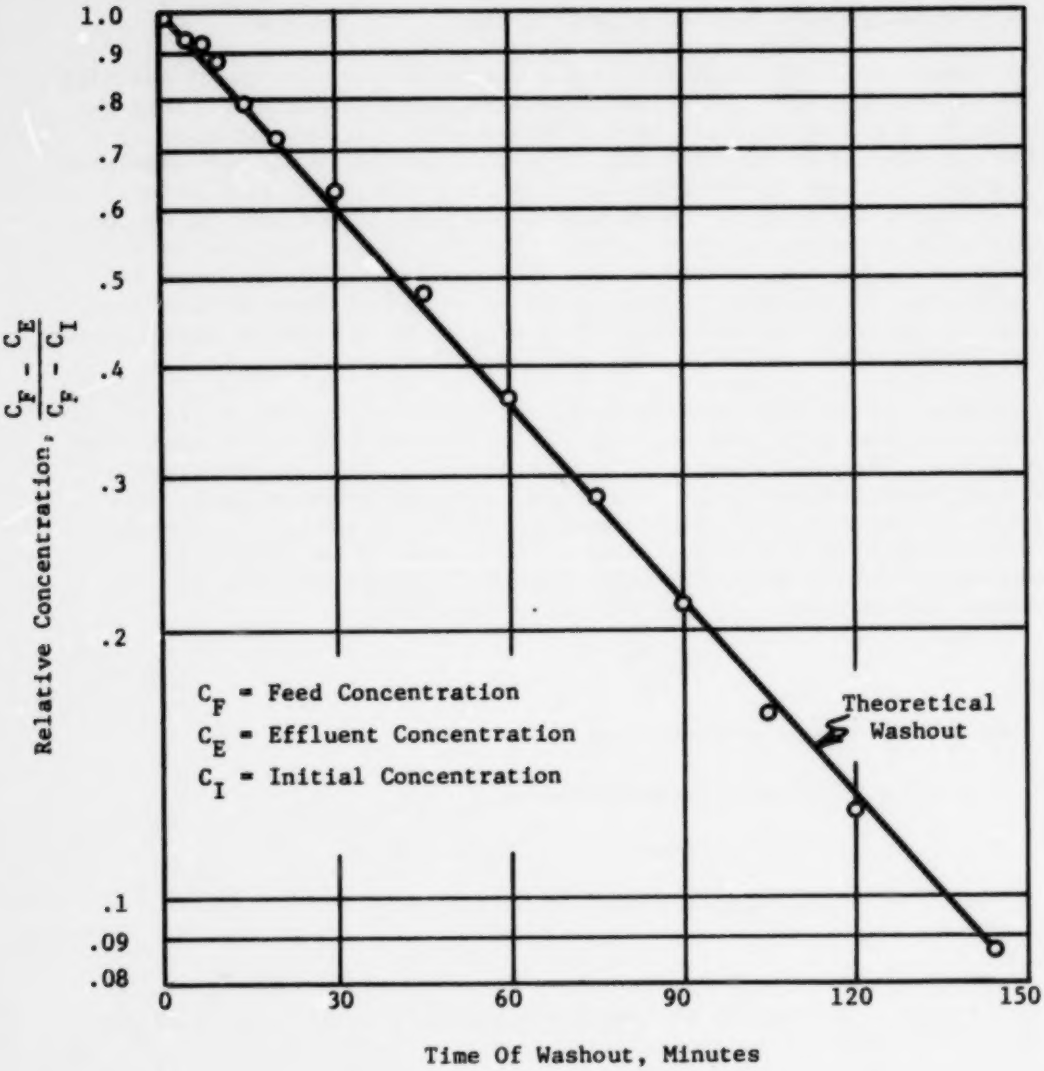


Figure 5. TRACER WASHOUT CURVE FOR THE KEHR PROCESS AERATION TANK

The data from the tracer washout also demonstrated the ability of a completely mixed aeration tank to buffer shock loadings as compared to a plug flow tank. The salt solution fed to the KASP aeration tank was a hundred times as concentrated as the fresh water initially in the tank. As the strong salt solution was added, it was immediately dispersed throughout the aeration tank, which resulted in a gradual increase in the salt concentration in the aeration tank. The washout data demonstrating this buffering phenomena are shown graphically in Figure 6. In a plug flow tank, the hundred fold increase would not be dispersed throughout the tank and would move through the tank as a highly concentrated core of salt water. If a hundred fold increase occurred in sewage strength, this same buffering phenomena of the completely mixed aeration tank would allow the microorganisms in the mixed liquor to react to a slowly changing environment rather than any sudden shock that would be experienced in a plug flow tank.

Continuous Operation of KASP - In the KASP as operated at CEL, no solids were removed from the system as a waste sludge stream. Therefore, the KASP could only remove carbonaceous matter and nutrients from the liquid waste by converting them to a gaseous form. Carbon, nitrogen, and phosphorus were the materials measured in this study and the removal of each of these by the KASP is presented in the following results.

The KASP was operated for 28 days of continuous operation during the Fall of 1967 and for 12 days during the Fall of 1968. Both industrial waste and domestic sewage were treated by the KASP during this continuous operation, and the dividing line between domestic and cannery waste was arbitrarily set at a BOD_5 concentration of 300 mg/liter. Because the canneries did not usually pack on the weekends, the sewage during the canning season was characterized by high concentrations of BOD_5 from Monday to Friday and low BOD_5 domestic waste on the weekend. After the canning season the sewage, which primarily consisted of domestic waste, had a fairly constant concentration of BOD_5 throughout the week.

Data showing the performance of the KASP stabilizing organic waste are shown in Figures 7 and 8. Figure 7 shows the TOC data while Figure 8 shows the data for BOD_5. On weekdays during the canning season, the KASP treated cannery wastes with concentrations of BOD_5 ranging up to 1550 mg/liter and achieved over 90 percent BOD_5 removal and 80 percent TOC removal. However, on the weekends the sewage strength decreased while the concentration in the effluent of both BOD_5 and TOC remained at about the same level as during the week. This caused a reduction in the percent removals of both TOC and BOD_5 during the weekends. The most illustrative example of this phenomena was Sunday, September 8, 1968 where the percent removal of BOD_5 dropped to 28.4 percent and the percent removal of TOC dropped to -48.4 percent.

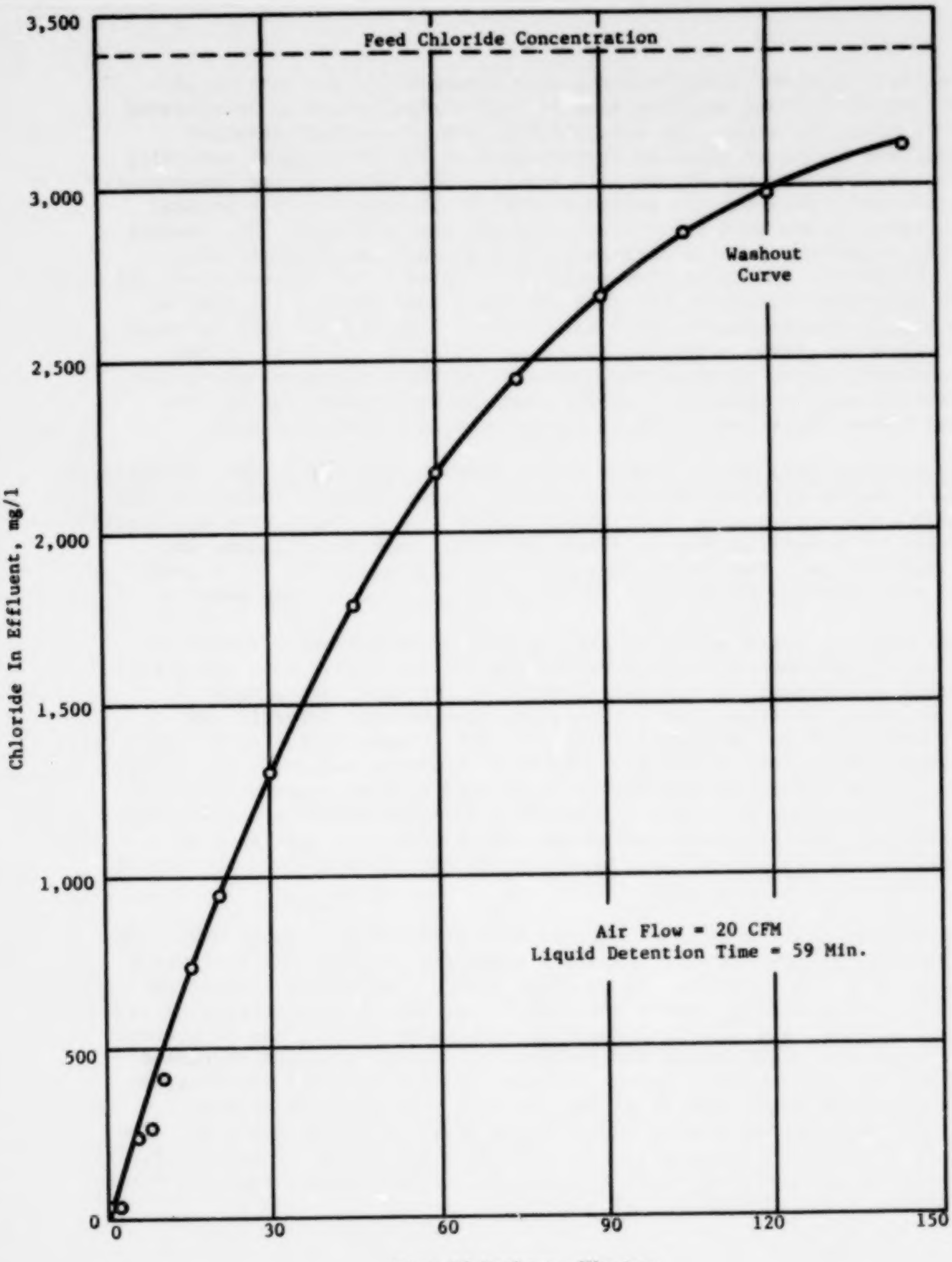


Figure 6. TRACER WASHOUT CURVE FOR THE KEHR PROCESS AERATION TANK

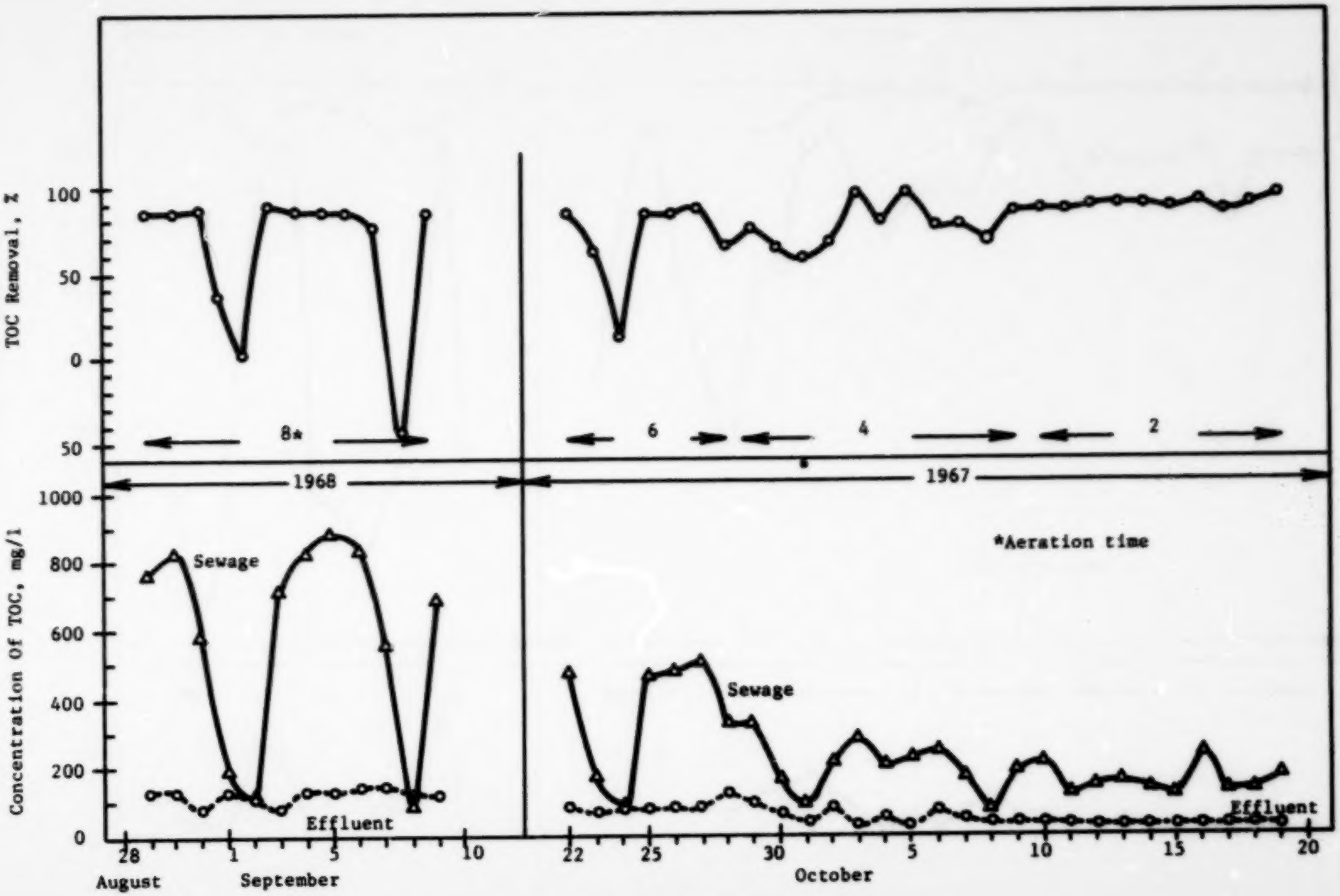


Figure 7. TOC DATA FOR THE KEHR PROCESS FOR CONTINUOUS OPERATION

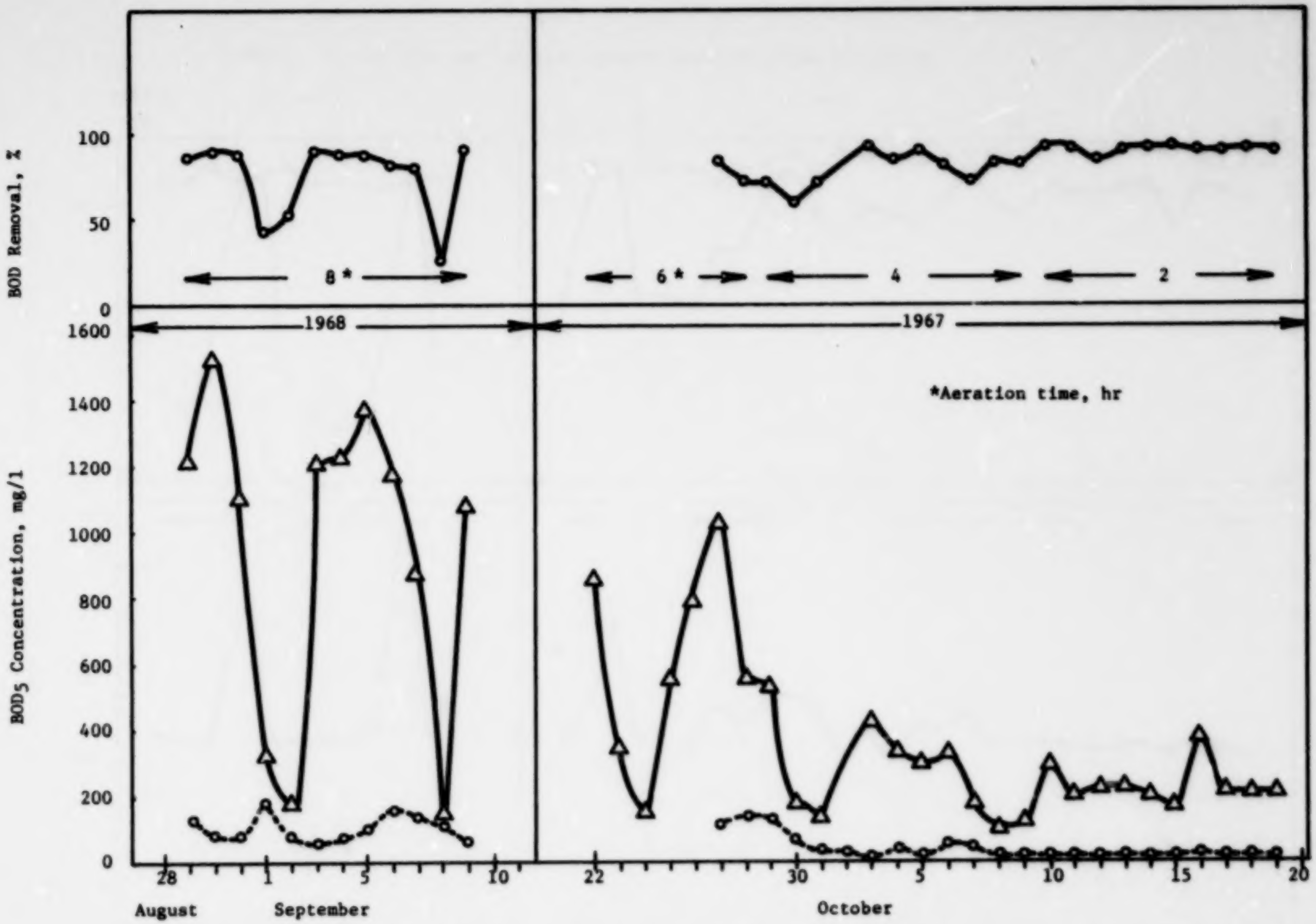


Figure 8. KEHR PROCESS BOD DATA FOR CONTINUOUS OPERATION

The nearly constant effluent quality is due in part to the inverse of the washout phenomena shown in Figure 6. Another factor that probably contributed to the nearly constant effluent quality is that the BOD_5 in the effluent is affected by the efficiency of the solids separation system which is somewhat independent of the influent BOD.

During the period when the KASP treated domestic sewage, the influent and effluent qualities were fairly constant yielding constant percent removals of carbonaceous materials measured as either BOD_5 or TOC. Because of the consistent sewage quality, the only shocking of the KASP came from the diurnal flow variation programmed into the system. During one 24-hour period the biological system was sampled every hour. Four-hour composites of the feed and effluent were made up and analyzed for TOC. The results of this test are shown in Figure 9. These data show that the KASP produces a very consistent effluent thereby damping out the variation in loading due to flow in a manner similar to that observed for the organic shocking during the canning season.

Based upon the 8-hour composite samples, the BOD_5 and TOC removals for each aeration period tested were calculated. The percent removals were calculated by summing the total amounts of BOD_5 and TOC in both the feed and effluent for each aeration period rather than on a daily basis. These percent removals are presented in Table 1 along with the number of days of operation at each aeration period.

Table 1. Cumulative BOD_5 and TOC Removals

Aeration Period	Cumulative BOD_5 Removal (%)	Cumulative TOC Removal (%)	Period of Operation
8 hours	88.9	80.2	11 days
6 hours	84.4	77.2	7 days
4 hours	85.7	77.1	9 days
2 hours	95.3	87.4	11 days
AVERAGE	88.5	80.4	

The operation of the KASP was such that the changes in aeration period coincided with changes in sewage strength and character resulting from seasonal fluctuations in cannery operation. For this reason as well as the short period of operation at each aeration period, the results at different aeration periods cannot be compared directly. However, the average removals of about 80 and 90 percent for TOC and BOD_5, respectively, do give some indication of the treatment efficiency of the KASP.

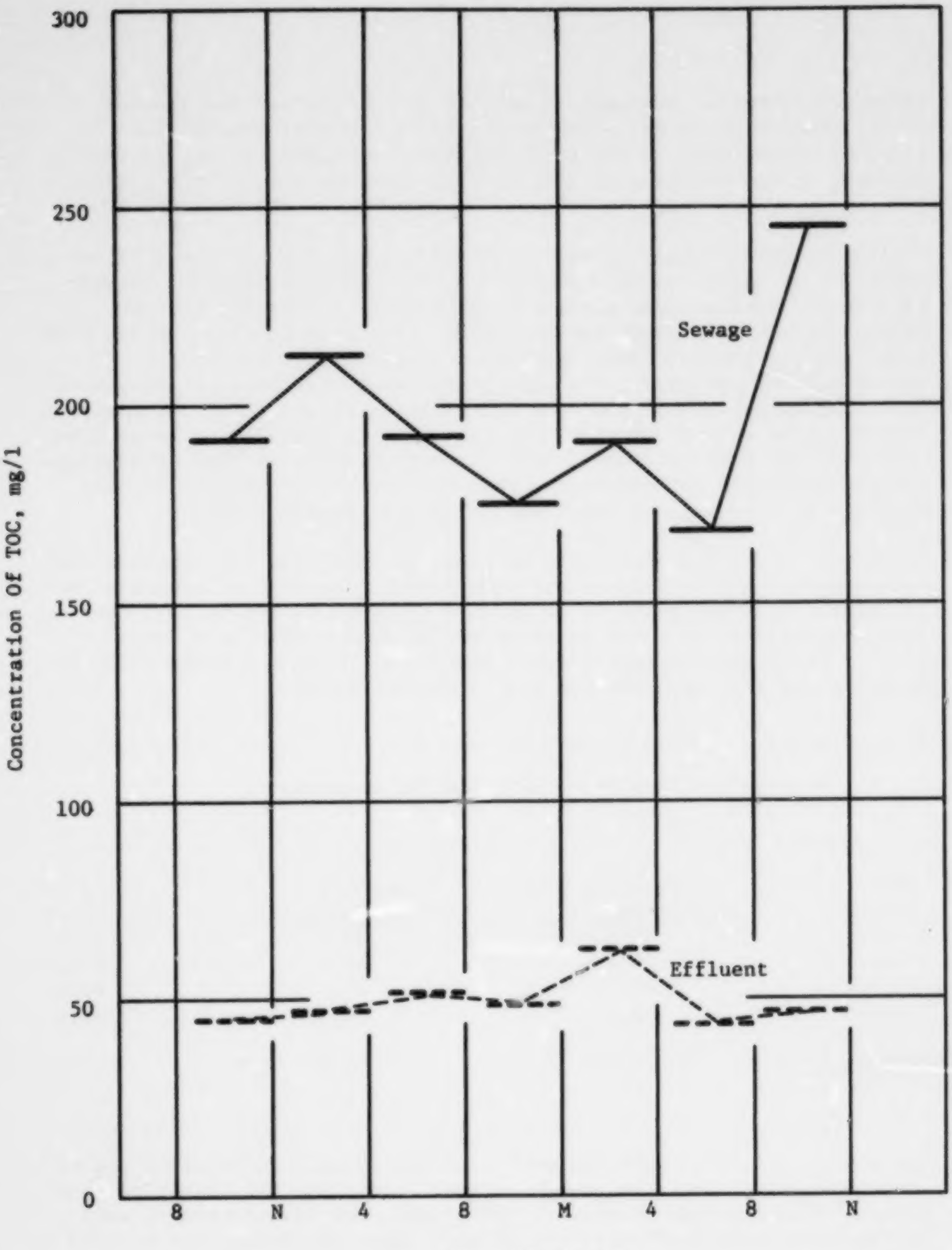


Figure 9. DIURNAL VARIATION OF KEHR PROCESS TOC

Using the average percent removals of BOD_5 based upon unfiltered samples, the rate constant for BOD removal for each aeration period can be calculated from equation 4. These data yield rate constants of 1.0, 0.9, 1.5, and 10.2 per hour for the 8, 6, 4, and 2-hour aeration periods, respectively. The weekday concentration of BOD_5 during the 8, 6, and 4-hour aeration periods was always greater than 300 mg/liter while for the 2-hour aeration period it was usually about 200 mg/liter. The fairly consistent values for the BOD removal rate constant of 0.9 to 1.5 per hour at the 8, 6, and 4-hour aeration periods were for sewage that contained industrial waste. The BOD removal rate constant of 10.2 per hour at the 2-hour aeration period was for domestic sewage and agrees well with the value of 15 per hour for domestic sewage reported by Smith (3).

It is interesting to note the nearly 10 fold difference in the calculated rate constants for the two wastes.

When designing a particular activated sludge treatment plant, one of the most important design parameters is the loading that the type of activated sludge being used operates under. Three different loading parameters were calculated from the data for operation of the KASP. The three are: the volumetric loading measured as the pounds of BOD_5 per day per thousand cubic feet of aeration tank and two forms of the organic loading which are measured as the pounds of BOD_5 per day per pound of mixed liquor suspended solids and as the pounds of BOD_5 per day per pound of mixed liquor volatile suspended solids.

The various loading parameters were not constant due to the lack of steady state conditions. For the KASP with no intentional sludge wasting the observed average loadings, excluding weekends, were 200 pounds of BOD_5 per day per thousand cubic feet of aeration tank capacity, 0.473 pounds of BOD_5 per day per pound of mixed liquor volatile suspended solids, and 0.418 pounds of BOD_5 per day per pound of mixed liquor suspended solids. It should be noted that the mixed liquor suspended solids were high in volatile matter. They were 85 to 90 percent volatile matter which is higher than the 75 percent found for many wastes.

The phosphate analyses on the sewage and effluent streams during the continuous operation are shown in Table 2. Because the system was sampled only during the eight-hour working day, a phosphate balance around the system could not be made due to diurnal variations in flow and waste strength. These variations caused alternate periods of phosphate accumulation and loss by the bio-mass which are unknown. However, it would be expected that an activated sludge system with no waste sludge would not remove phosphate from the liquid waste. This is shown in Table 2 where little or no phosphate removal is recorded.

Table 2. Kehr Process Influent and Effluent Phosphate Concentrations

		Total Concentration of Phosphate in mg/liter*	
Date	Aeration Period	Sewage	Effluent
8/29/68	8 hours	19.2	14.2
8/30/68	"	58.0	18.5
8/31/68**	"	41.8	18.5
9/1/68***	"	50.7	23.0
9/2/68****	"	44.4	36.4
9/3/68	"	—	35.3
9/4/68	"	31.1	26.1
9/5/68	"	32.0	19.9
9/6/68	"	26.0	27.0
9/7/68**	"	20.5	17.5
9/8/68***	"	58.9	29.7
9/9/68	"	41.1	24.4
9/22/67	6 hours	28.6	14.2
9/23/67**	"	35.8	11.6
9/24/67***	"	26.6	21.8
9/25/67	"	24.8	23.8
9/26/67	"	20.6	17.6
9/27/67	"	23.4	18.4
9/28/67	"	42.4	28.6
9/29/67	4 hours	50.0	32.6
9/30/67**	"	57.2	29.4
10/1/67***	"	23.8	26.4
10/2/67	"	54.2	51.4
10/3/67	"	51.2	10.8
10/4/67	"	30.2	36.6
10/5/67	"	33.4	21.6
10/6/67	"	40.4	25.2
10/7/67**	"	77.6	32.6
10/8/67***	"	22.6	31.0
10/9/67	"	38.0	30.6
10/10/67	2 hours	28.6	25.6
10/11/67	"	23.4	23.6
10/12/67	"	29.4	22.4
10/13/67	"	27.4	30.2
10/14/67**	"	28.6	27.2
10/15/67***	"	29.2	26.2
10/16/67	"	29.2	29.4
10/17/67	"	28.6	25.2
10/18/67	"	28.8	28.8
10/19/67	"	27.2	23.8

* As PO_4
** Saturday
*** Sunday
**** Labor Day

The results for the nitrogen analyses are shown in Table 3 and 4. During the period of continuous operation, the nitrogen present in the effluent from the KASP was primarily in the ammonia or organic form with little or no nitrite or nitrate present. The general trend was that as the BOD_5 of the sewage increased, more of the effluent nitrogen was in the organic form. With high strength cannery waste nearly 100 percent of the effluent nitrogen was in the organic form while the domestic sewage only about 15 percent of the nitrogen was organic with most of the remainder being ammonia.

Because no waste sludge was removed,the removal of nitrogen from the liquid waste would be expected to be a minimum. However, the data show apparent nitrogen removals of 62, 66, 53, and 48 percent for the intervals operated at aeration periods of 8, 6, 4, and 2-hours, respectively. These removals are based upon 8-hour composite samples and may be explained in part by the diurnal variation in sewage flow and strength. The eight-hour working day follows a period of low flow and low sewage strength and therefore would be a period of synthesis, which causes accumulation of nitrogen by the bio-mass. This accumulation would tend to be released during the low flow period when no samples were taken. Also complete balance for nitrogen around the KASP system is not possible without analyzing the composition of the off gases.

A 28-hour sampling program was conducted on the KASP effluent and sewage in an attempt to provide more complete phosphate and nitrogen analyses for the KASP. Grab samples of sewage and effluent were taken every hour and made up into four-hour composites. The nitrogen and phosphate analyses on these composites are shown in Figures 10 and 11.

For both the nitrogen and phosphate, the difference between the concentration in the sewage and that in the effluent decreased through the first 24 hours. Then during the first 4 hours of the second day this difference increased again. The sludge was not analyzed and during this 28 hours it was not possible to complete a nutrient balance using the feed and effluent concentration alone.

Artificial Shock Loading - To better study the effect of shock loading conditions on the KASP, an artificial shock loading was imposed on the system. For 48 hours fresh water was fed to the bio-mass and then sewage (BOD_5 of 230 and 180 mg/liter) was fed for the following 48 hours. The aeration time for the study was 2 hours. The response of the biological system to the artificial shock loading as measured by the effluent concentrations of BOD_5, TOC, and suspended solids is shown in Figures 12 through 14. During the water feed, there was a washout of nutrients from the aeration tank. The concentrations decreased rapidly and then appeared to level off. Therefore due to the washout phenomena, the fresh water feed improved the effluent quality over that prior to the study.

Table 3. Nitrogen Data For Kehr Process Sewage

Date	Aeration Period	NH_3*	Organic-N*	NO_2*	NO_3*	Total N*
8/29/68	8 hours	6.65	18.60	--	1.35	26.60
8/30/68	"	4.60	16.80	--	0.88	22.28
8/31/68**	"	5.36	15.10	--	1.10	21.56
9/1/68***	"	5.65	10.90	--	0.72	17.27
9/2/68****	"	28.00	15.10	--	0.38	43.48
9/3/68	"	9.30	20.70	--	0.50	30.50
9/4/68	"	7.57	19.50	--	0.28	27.35
9/5/68	"	6.41	--	--	2.36	--
9/6/68	"	6.70	21.30	--	1.54	29.54
9/7/68**	"	6.99	13.10	--	1.55	21.64
9/8/68***	"	6.99	6.41	--	1.15	13.09
9/9/68	"	8.30	17.80	--	0.95	27.05
9/22/67	6 hours	7.0	13.1	--	1.00	21.10
9/23/67**	"	9.3	12.1	--	--	21.40
9/24/67***	"	29.9	11.1	--	--	41.00
9/25/67	"	14.1	13.6	--	0.98	26.68
9/26/67	"	8.6	16.6	--	0.96	28.68
9/27/67	"	6.9	16.2	--	0.82	23.92
9/28/67	"	10.0	10.1	--	0.54	20.64
9/29/67	4 hours	12.0	10.1	--	0.85	22.95
9/30/67**	"	24.4	10.8	--	0.18	35.38
10/1/67***	"	27.5	10.2	--	0.08	37.78
10/2/67	"	18.1	8.9	--	--	27.00
10/3/67	"	14.6	11.1	--	--	25.70
10/4/67	"	15.6	7.5	--	--	23.10
10/5/67	"	16.0	9.8	--	--	25.80
10/6/67	"	17.2	11.3	--	--	28.50
10/7/67**	"	23.0	10.0	--	--	33.00
10/8/67***	"	32.2	10.7	--	--	42.90
10/9/67	"	34.4	9.1	.01	--	43.51
10/10/67	2 hours	21.9	11.3	.01	0.16	33.37
10/11/67	"	20.3	10.3	Trace	--	30.60
10/12/67	"	20.6	13.0	--	0.19	33.79
10/13/67	"	15.6	3.8	Trace	0.78	20.18
10/14/67**	"	24.0	10.3	Trace	0.13	34.43
10/15/67***	"	108.2	9.6	--	--	117.80
10/16/67	"	21.6	6.4	Trace	1.36	33.62
10/17/67	"	15.3	11.1	--	0.92	27.32
10/18/67	"	14.3	10.5	--	0.92	25.72
10/19/67	"	19.7	11.1	--	0.92	31.72

*	Values given are in mg/liter as Nitrogen
**	Saturday
***	Sunday
****	Labor Day

Table 4. Nitrogen Data For Kehr Process Effluent

Date	Aeration Period	NH_3*	Organic-N*	NO_2*	NO_3*	Total N*
8/29/68	8 hours	--	9.04	--	0.20	9.24
8/30/68	"	--	7.05	--	0.18	7.23
8/31/68**	"	--	10.00	--	0.10	10.10
9/1/68***	"	--	5.45	--	0.10	5.55
9/2/68****	"	--	12.20	--	0.10	12.30
9/3/68	"	--	8.40	--	0.06	8.46
9/4/68	"	--	10.50	--	0.35	10.85
9/5/68	"	--	--	--	0.60	--
9/6/68	"	--	11.07	--	0.29	11.36
9/7/68**	"	--	10.77	--	--	10.77
9/8/68***	"	--	9.61	--	0.31	9.91
9/9/68	"	0.5	8.90	--	0.29	9.69
9/22/67	6 hours	1.2	7.2	--	--	8.40
9/23/67**	"	--	5.4	--	--	5.40
9/24/67***	"	2.3	4.3	--	--	6.60
9/25/67	"	9.8	4.0	--	0.18	13.98
9/26/67	"	4.8	5.2	--	0.36	10.36
9/27/67	"	2.8	5.2	--	0.22	8.22
9/28/67	"	3.1	5.9	--	0.40	9.40
9/29/67	4 hours	2.0	6.4	--	--	8.40
9/30/67**	"	1.2	4.2	--	0.22	5.62
10/1/67***	"	11.7	3.5	--	--	15.20
10/2/67	"	15.7	5.2	Trace	--	20.90
10/3/67	"	7.0	2.3	Trace	--	9.30
10/4/67	"	4.4	4.2	Trace	--	8.60
10/5/67	"	10.3	2.0	Trace	--	12.30
10/6/67	"	11.6	5.4	Trace	--	17.00
10/7/67**	"	6.5	3.2	Trace	--	9.70
10/8/67***	"	23.7	2.7	Trace	--	26.40
10/9/67	"	27.0	3.2	0.01	--	30.21
10/10/67	2 hours	16.8	11.8	--	--	28.60
10/11/67	"	15.0	3.3	Trace	--	18.30
10/12/67	"	16.8	3.3	Trace	0.12	20.22
10/13/67	"	16.3	2.3	--	--	18.60
10/14/67**	"	14.5	2.4	Trace	--	16.90
10/15/67***	"	26.8	2.0	--	--	28.80
10/16/67	"	23.8	3.2	--	0.06	27.06
10/17/67	"	10.1	3.5	--	--	13.60
10/18/67	"	13.4	2.0	--	0.07	15.47
10/19/67	"	13.7	1.7	--	0.06	15.46

*	Values given are in mg/liter as Nitrogen
**	Saturday
***	Sunday
****	Labor Day

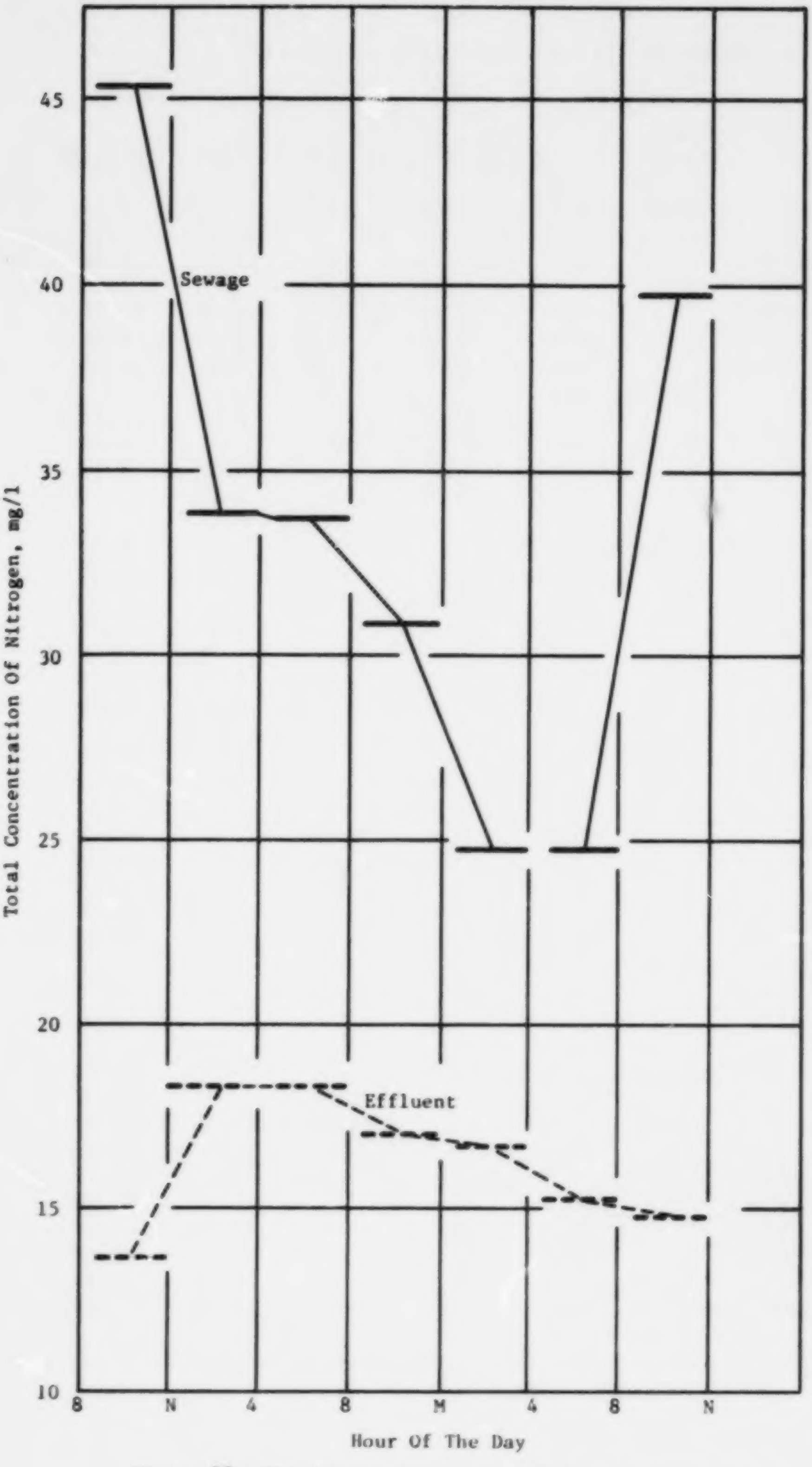


Figure 10. DIURNAL VARIATION OF KEHR PROCESS NITROGEN

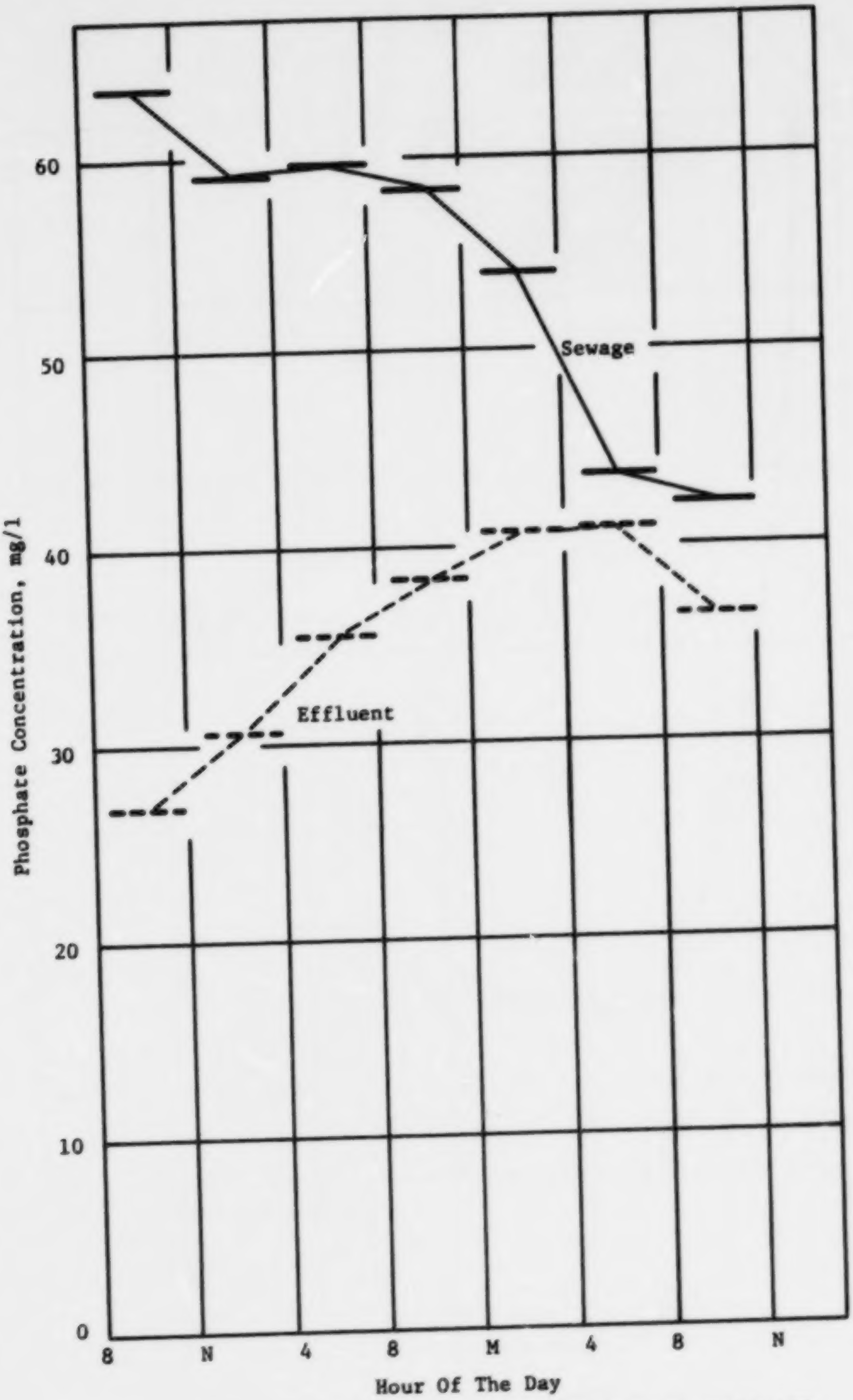


Figure 11. DIURNAL VARIATION OF KEHR PROCESS PHOSPHATE

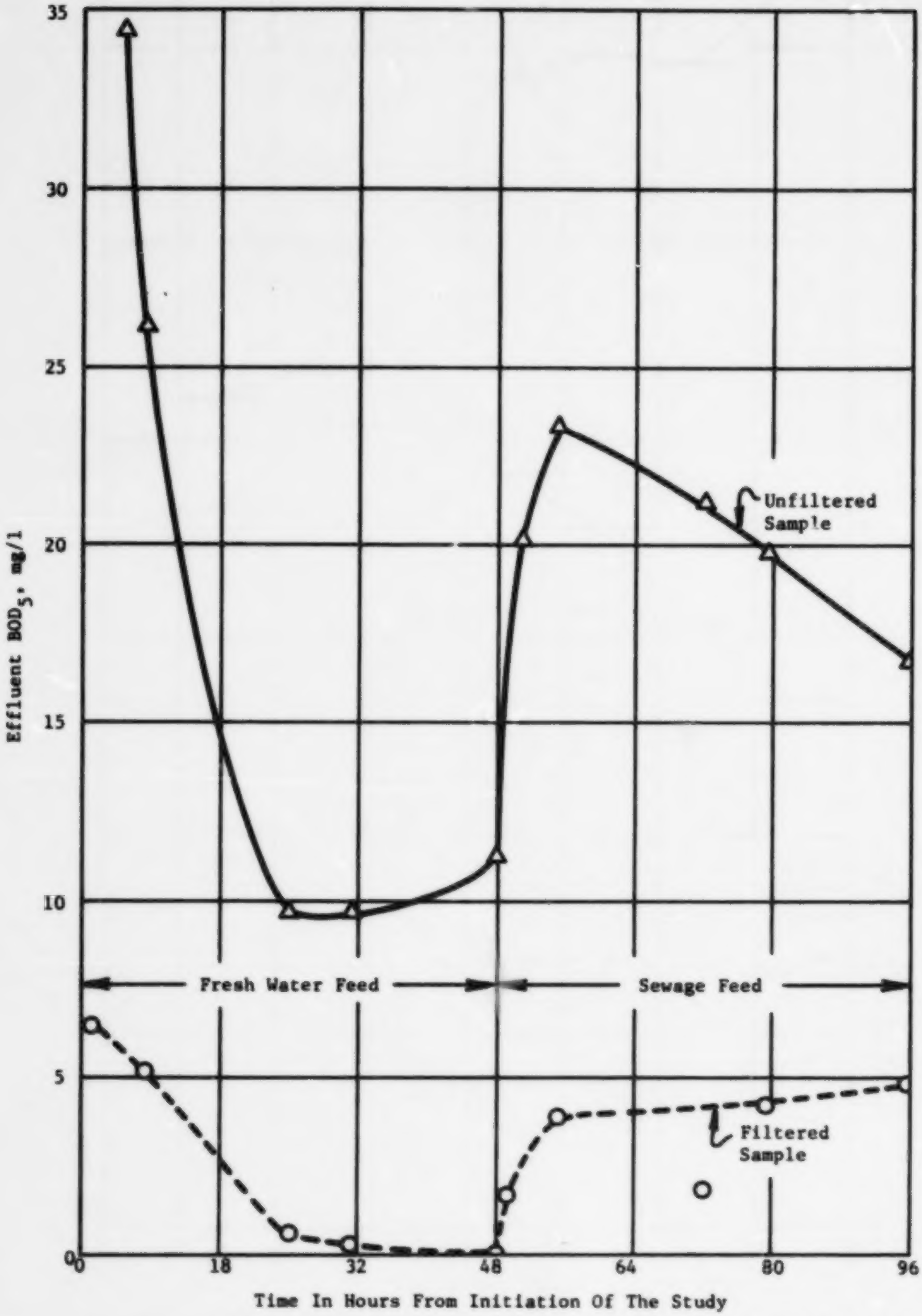


Figure 12. EFFLUENT BOD_5 AS A FUNCTION OF TIME FOR THE SHOCK LOADING STUDY

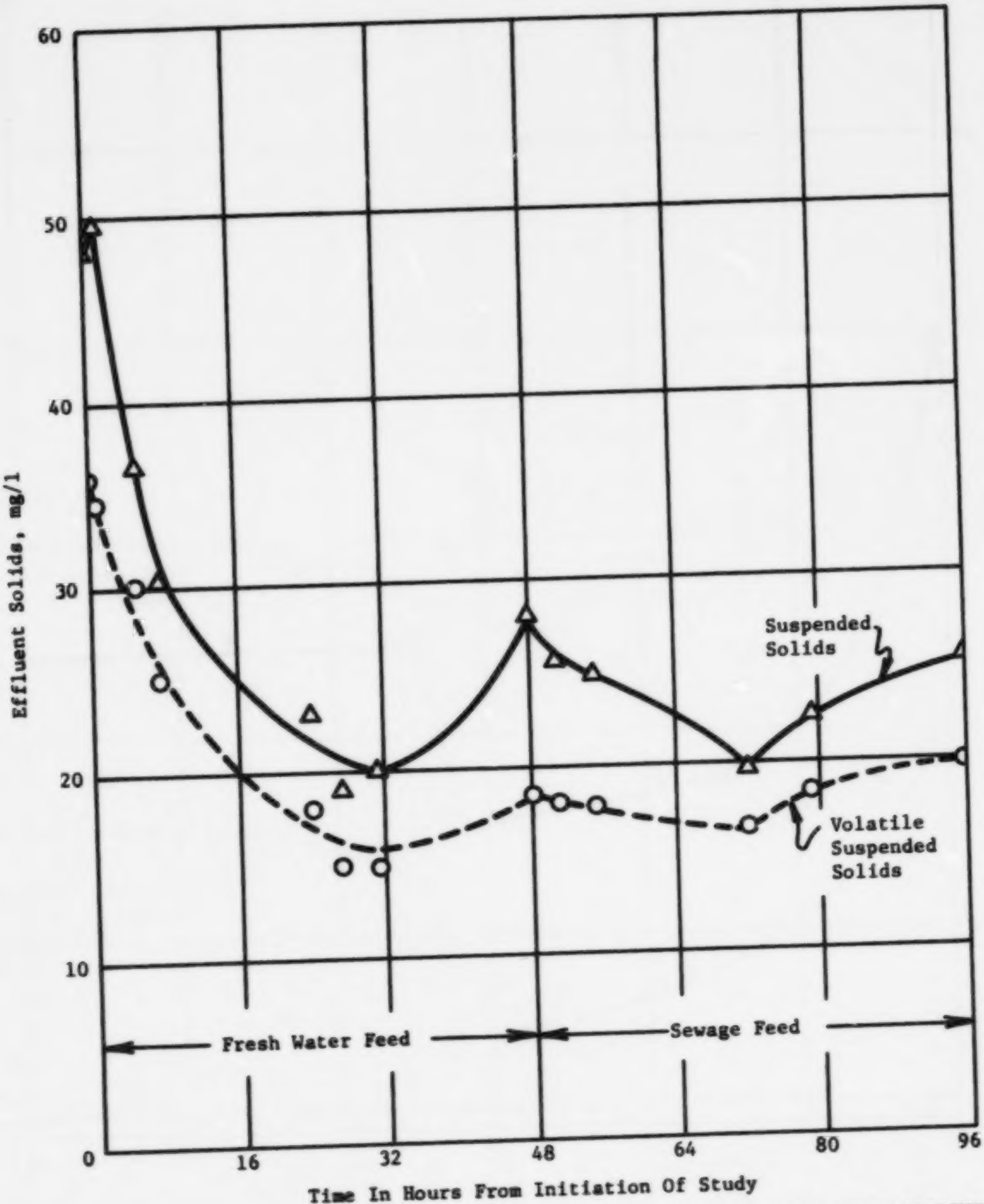


Figure 13. EFFLUENT SUSPENDED SOLIDS AS A FUNCTION OF TIME FOR THE SHOCK LOADING STUDY

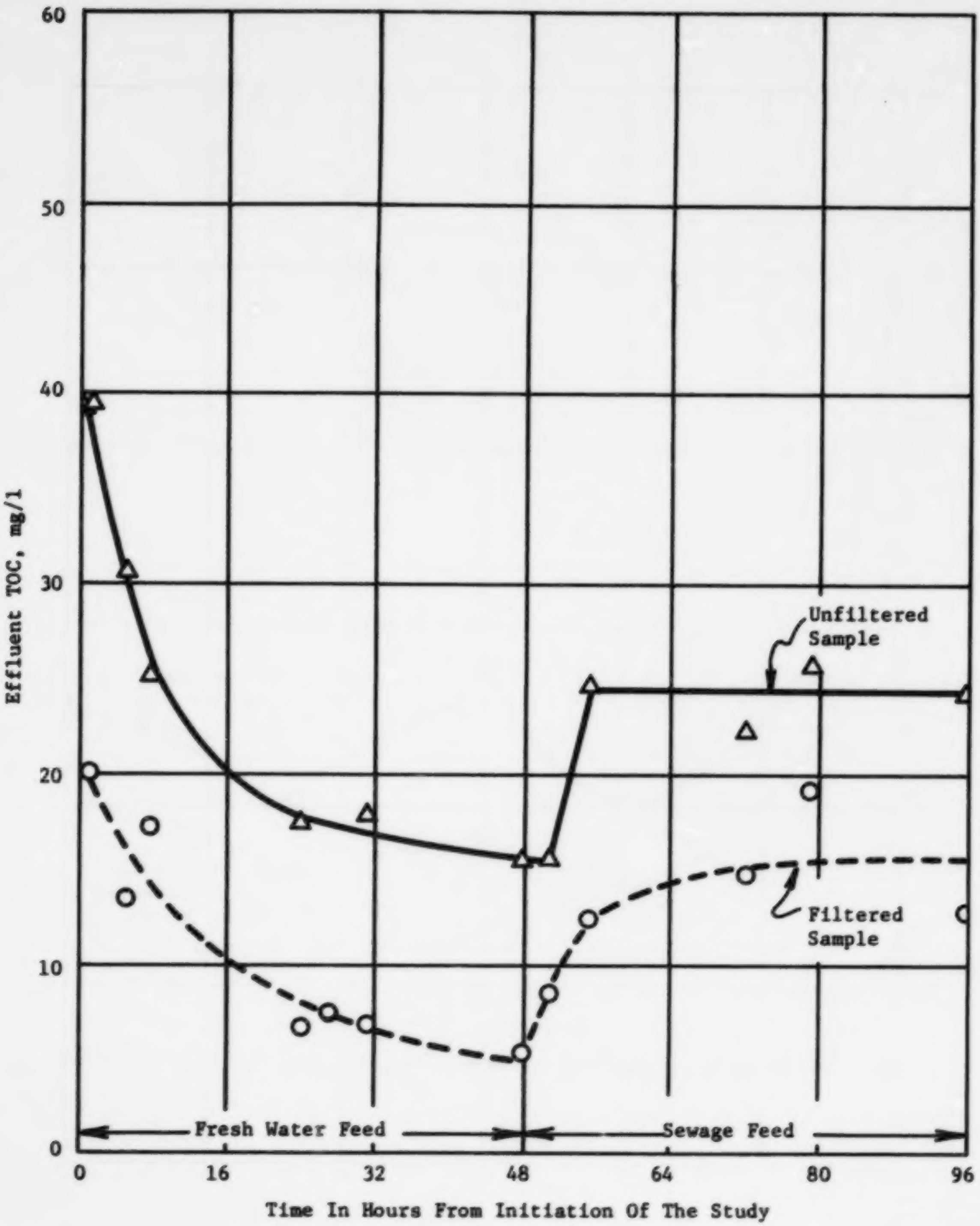


Figure 14. EFFLUENT TOC AS A FUNCTION OF TIME FOR THE SHOCK LOADING STUDY

The concentration of BOD_5 in the filtered effluent dropped to nearly zero indicating that little biodegradable substrate was present in solution. Because no food for the bio-mass was present in solution, the production of new cellular mass was reduced causing cell death and lysing to predominate over synthesis. The concentrations of TOC, BOD_5, and suspended solids in the effluent after they leveled off probably corresponded to loss into the effluent due to cell lysing.

After the sewage was turned back on, a rapid and immediate increase was observed in the effluent concentrations of both the BOD_5 and TOC. This rapid increase was followed by a leveling off of the TOC and filtered BOD_5. The filtered BOD_5 and TOC reached a level nearly the same as that before the initiation of the water feed while the level of TOC was less than before the water feed. The concentration of unfiltered BOD_5 decreased after the initial rapid increase. The sewage feed produced little change in the concentration of suspended solids.

It is interesting to note that the KASP was able to go without any organic loading for 48 hours with no apparent loss of treatment efficiency when the organic load was returned. The KASP would seem to be able to adequately handle wastes of periodic discharge.

The shock loading also had an effect, shown graphically in Figure 15, upon the concentration of nitrogen and phosphate in the effluent. During the fresh water feed, the concentrations of both decreased rapidly to a fairly steady state value probably corresponding to the rate of cell lysing. Upon the initiation of the sewage feed, the concentrations of both increased rapidly but the concentration of nitrogen soon leveled off well below the concentration in the sewage while the phosphate increased in concentration to that in the sewage.

DISCUSSION

The operation of the KASP biological system using gravity settling was very effective in BOD_5 and solids removal and performed with no major difficulties. Once the air and liquid flows were set, the system required no attention except for sampling and mechanical maintenance. The biological system performed well throughout its operation except for the period of July 9th through July 11th, 1968 when the pH of the sewage ranged from 9.2 to 11.2. This high pH waste raised the pH of the mixed liquor to 9.7, which adversely affected most of the mixed liquor bio-mass because little or no active microbiological life was observed by microscopic examination.

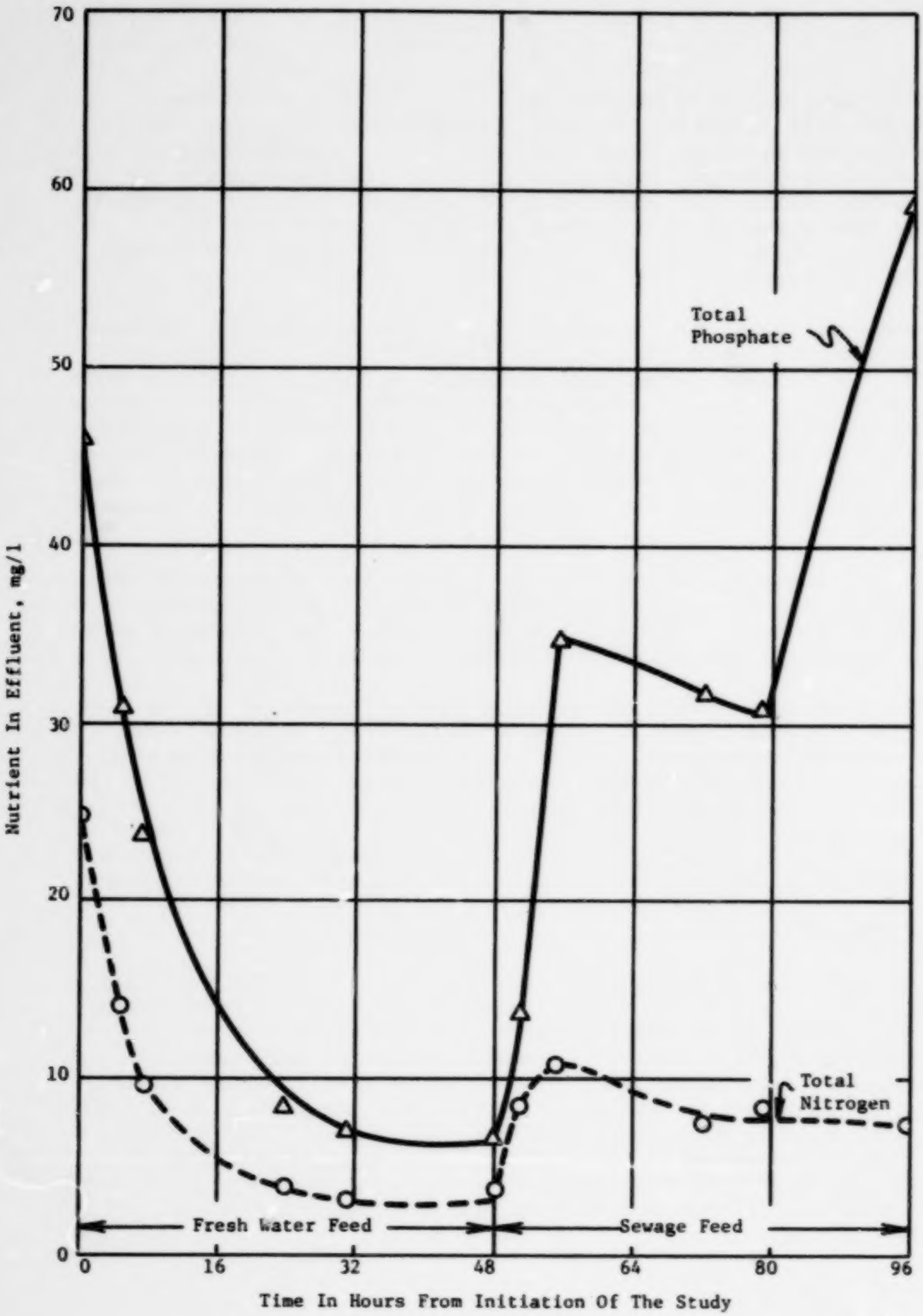


Figure 15. EFFLUENT NUTRIENT CONCENTRATION AS A FUNCTION OF TIME FOR THE SHOCK LOADING STUDY

The operation of the KASP showed that aerobic digestion could be obtained in the aeration tank of a completely mixed activated sludge plant at aeration times from 2 to 8 hours. This was done by having no intentional wasting of sludge and operating such that the concentration of mixed liquor solids stabilized at about 10,000 mg/liter. The KASP produced about a 90 percent reduction in BOD_5 but the KASP does have features that can limit its application.

One limitation is the low removal of TOC. Organic carbon is present in the raw waste in two forms, non-biodegradable carbon and biodegradable carbon. Non-biodegradable carbon is unaffected by microbiological activity and therefore would not be removed by the KASP or any other activated sludge process. This portion of the organic waste will pass through unchanged and therefore limit the amount of carbon that can be removed from the influent waste. In the KASP, most of the biodegradable carbon, measured as BOD_5, was readily converted to a settleable activated sludge mass and carbon dioxide allowing high removals of BOD_5. However, a portion of the settleable sludge mass cannot be biodegraded. Therefore, it cannot be oxidized and removed as carbon dioxide. In conventional activated sludge treatment, some of this non-biodegradable sludge is removed as waste activated sludge. The KASP differed from conventional activated sludge treatment in that no solids were intentionally wasted from the system. Therefore the non-biodegradable sludge mass formed by the KASP must either remain in the aeration tank or be washed out as organic carbon in the effluent. McKinney (2) indicates that for complete oxidation systems, approximately 10 to 13 percent of the biodegradable organic matter being treated will appear in the effluent as inert solids. For the operation of the KASP, the removal of organic carbon was usually about 80 to 85 percent. The effluent from the KASP was high in turbidity and color and did not have the sparkling appearance that is observed in the effluent from a well run activated sludge plant that produces waste activated sludge. The increase in color and turbidity over a conventional activated sludge plant is probably due to the added carbon carried into the effluent.

Because no waste activated sludge stream is removed from the KASP, no inorganic nutrients are removed with the waste sludge. However, in a conventional activated sludge plant inorganic nutrients are removed with waste activated sludge. Therefore, BOD removal is the only area where the KASP can equal the performance of an activated sludge plant that produces waste sludge.

One logical extension of the KASP is increasing the volumetric BOD_5 loading and thereby increasing the substrate level and correspondingly the concentration of mixed liquor solids. The increased loading results in a smaller aeration tank and reduced costs. However, the BOD_5 loading can only be increased if there is sufficient aeration capacity to supply the increased oxygen demand that the increased loading would require. Therefore, the BOD loading and the steady state concentration of solids in the mixed liquor is limited by the aeration capacity. For this study, 10,000 mg/liter was thought to be a good compromise.

The KASP provides a lower removal of TOC, nitrogen and phosphorus than can be achieved from a conventional activated sludge plant that provides a waste sludge, but the KASP offers other advantages. The KASP was found to be able to produce a high degree of treatment of sewage following 48 hours with no organic loading.

One possible use of the KASP that will profit from its advantages and not be hindered by its disadvantages is the treatment of high strength industrial wastes prior to their discharge into a municipal sewer. The municipal treatment plant would benefit from the reduction in BOD_5. Some of the advantages of the KASP that the industry could benefit from are give below.

The KASP provides simple operation requiring no waste sludge handling facilities. The KASP has the ability to withstand long periods of no organic loading for industries that do not work over weekends or do not have 24-hour a day production.

The KASP appears to be a suitable form of waste treatment where about a 90 percent removal of BOD_5 is desired and where little removal of either phosphorus or nitrogen, as well as only an 80 percent removal of organic carbon, is acceptable.

An activated sludge plant such as the KASP using no intentional sludge wasting and operating on the principal of steady state concentration of active mass appears to have an application for treating industrial wastes. As illustrated by the 10 fold difference in the BOD removal rate constants found in this study, each waste has its own characteristics. Therefore, prior to the installation of an activated sludge plant such as the KASP, it is desirable to operate a pilot plant to determine the necessary design parameters for each individual waste.

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CONCENTRATION OF SUGARBEET WASTES FOR ECONOMIC TREATMENT WITH BIOLOGICAL SYSTEMS

by

Ronald W. Brenton and James H. Fischer*

INTRODUCTION

The people of the United States consume about 10 million tons of sugar annually, or slightly under 100 pounds per person. Of this total, about 30 percent comes from domestic sugarbeets (6). Beet sugar is produced at 58 factories located in 19 states from California to Maine and from Arizona to North Dakota. The processing of sugar from sugarbeets takes place at climatic locations and at times of the year ranging from a high of 120°F. in the Imperial Valley of California to a low of -40°F. in the Red River Valley of Minnesota and North Dakota. The sugarbeets being processed may have been freshly harvested or may have been in open-pile storage for some 100 days.

With these vastly different conditions in mind it is easy to understand that no single type of waste treatment system will operate with equal success at all locations. The quantity and quality of factory wastes do vary somewhat from factory to factory, however, the basic nature of the system wastes remains quite similar.

McGinnis and Weckel (4) report that little or no attention was given to waste disposal in the beet-sugar industry until recent years. Complete waste treatment in conformance with modern standards would require the equivalent of an average-sized municipal treatment plant for each factory. Such treatment is additionally complicated by the seasonal operations of the factories.

Beet-sugar factory wastes may be classified according to Eldredge (2) as to source. They are: flume water; process water, lime cake drainage; and Steffen or final waste when the Steffen process is used.

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Figure 1 is a typical diagram of the hydraulic flow in an average modern sugarbeet factory. Those streams associated with waste and byproduct disposal are shown. The sugarbeet, being a root crop, brings with it to the factory high quantities of dirt and organic particles. A high volume of water is required to flume and wash the roots prior to the actual process of extracting and refining the sugar. The fluming and washing waters become one of the most difficult of the wastes to treat since it accounts for the largest portion of the waste on a volume basis. Although water conservation practices are being exploited, 2200 gal. of water are required per 1 ton of sugarbeets for fluming and washing operations (2).

Hungerford has (3) reported on work in Nebraska where large grass fields were used to replace and follow the typical lagoons and ponds to treat factory wastes. The encroachment of metropolitan areas near to sugar factories has placed more emphasis on concentrating treatment systems into smaller land areas. Ponds and lagoons do not accomplish this unless they are accompanied by additional treatment. Norman et al.(5) determined that a laboratory activated sludge unit and a pilot plant trickling filter unit could work to serve such a purpose provided that large changes in pH could be avoided as well as overloading.

In a report on water conservation in the beet sugar industry Browning (1) states that recirculation of water used for fluming beets is a common practice. The recirculation he mentioned is partial, without supplementary treatment and not complete. Unpublished reports from Europe have indicated success with complete recirculation accompanied by continuous lime addition. This paper deals with total recirculation of limed flume water and concentration of the dissolved and suspended solids in the mud and recirculating water.

METHODS AND MATERIALS

It was determined that a full-scale closed-loop recirculating flume water system was to be constructed at Longmont, Colorado. A schematic diagram of the plan is shown on Figure 2. Construction began during the spring of 1967 and was completed by September 1967 in time for the system to become 100 percent operative as an integral part of the Longmont Factory of The Great Western Sugar Company. A fully-equipped mobile laboratory which contained the typical analytical hardware was placed near the treatment system. The system was designed to treat only those waters used in the fluming and washing operations.

Relatively few changes were made in the fluming system *per se*; the water treatment began after the delivery of sugarbeets past the final spray wash.

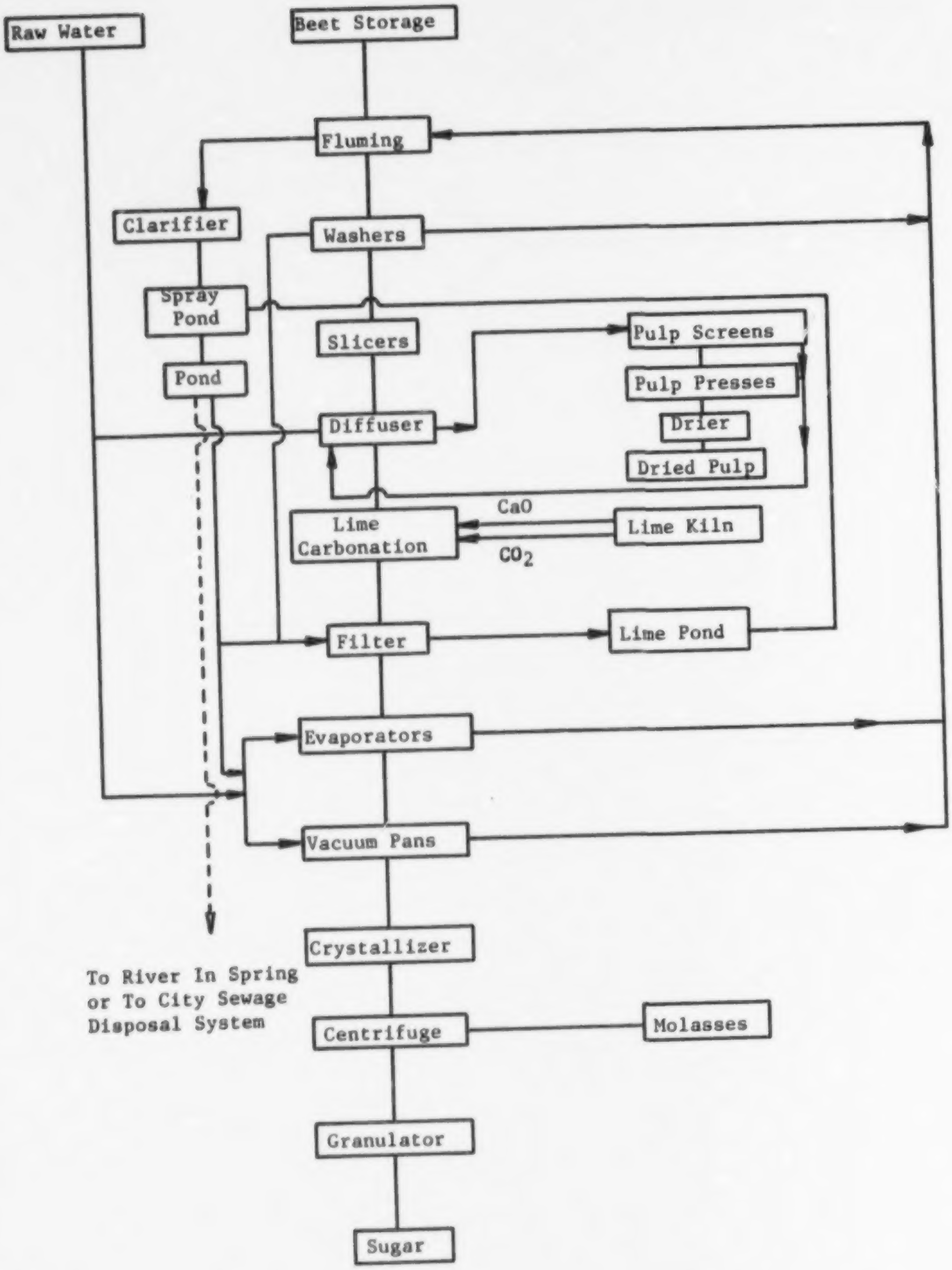
Raw Water
Beet Storage
Fluming
Clarifier
Washers
Spray Pond
Slicers
Pulp Screens
Pond
Pulp Presses
Diffuser
Drier
Dried Pulp
CaO
Lime Carbonation
Lime Kiln
CO_2
Filter
Lime Pond
Evaporators
Vacuum Pans
Crystallizer
To River In Spring or To City Sewage Disposal System
Centrifuge
Molasses
Granulator
Sugar

Figure 1. WATER FLOW DIAGRAM FOR A TYPICAL SUGARBEET FACTORY

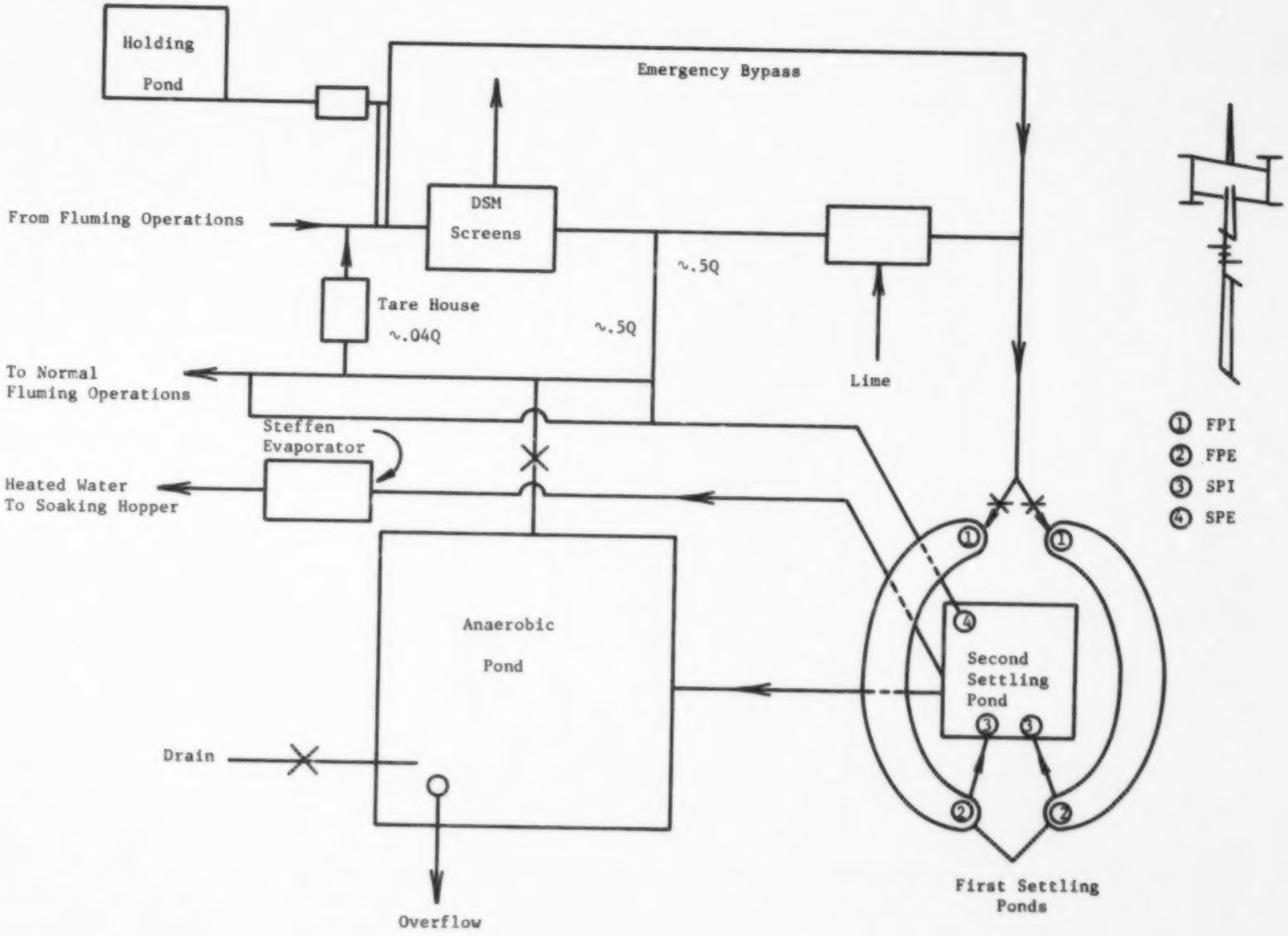
Holding Pond
Emergency Bypass
From Fluming Operations
DSM Screens
~.5Q
Tare House
~.04Q
~.5Q
Lime
To Normal Fluming Operations
Steffen Evaporator
Heated Water To Soaking Hopper
Anaerobic Pond
Drain
Overflow
Second Settling Pond
First Settling Ponds
① FPI
② FPE
③ SPI
④ SPE

Figure 2. SCHEMATIC FLOW DIAGRAM, LONGMONT FLUME WATER TREATMENT SYSTEM.

The flume water flow, which averaged 5000 to 6000 gpm, was first screened thru five Dorr-Oliver parabolic screens, and then was split. One-half of the flow returned directly to the flumes and the other half was mixed with a hot lime slurry and sent to the ponding system.

The ponding system was composed of two primary settling ponds (first ponds) which received the limed flume water. The two-pond arrangement allowed for cleaning of one pond while the other pond was in operation.

The flow from the first pond entered the second settling pond which was located in the middle of the two first ponds (Figure 2). The effluent from the second pond went back to the fluming operations. The anaerobic pond received any excess water from the second pond and received the flume water at end of campaign. Arrangements were available to use anaerobic pond water for make up to the system if needed and available.

Flume water could also be sent to a holding pond as an emergency in the event the system accumulated too much water. Flume water could also bypass the screens enroute to the settling ponds in situations which required more water than could be screened, again an emergency provision.

Condenser water could be added to the transport water for fluming beets during cold weather periods when heat was required to thaw frozen beets from rail cars. Facilities were designed for the second-year operation to heat the second pond effluent water for the aforementioned purpose, thus reducing the build up of system waters by direct addition of condenser water.

PROCEDURES

The experimental procedure and objectives included the following:

1. To operate the flume water system at various pH levels (which were to be achieved and maintained by the addition of differential amounts of lime). To determine: the effects of pH on the system; the effects of the system on the factory's ability to control the pH; the most economically feasible, yet operationally acceptable, pH range; the amount of pollution reduction achieved by the ponding system and the amount of residual pollution which would build up in the system water; and the biological characteristics of the ponding system.

2. To study the flume water after the beet processing season to determine: the rate of degradation; the eventual fate of various flume water components; the operational parameters (nutrient addition, aeration, etc.) which would achieve the most rapid and complete biodegradation.

During the beet processing season 24-hour composite samples were taken from the first pond influent, first pond effluent, and second pond effluent. These samples were taken and analyzed five days per week.

After the beet processing season, the flume water was discharged to the anaerobic pond. Samples were taken from various depths at two points on this pond. The individual samples were composited and analyzed from one to two times per week.

RESULTS

Recirculating Water, During Campaign

During the first six weeks of the processing campaign it was found that pH levels above 10.0 could be maintained with as little as from 200 to 300 lbs of lime per hour added to a flow rate of about 3000 gpm, (Figure 3) but once the pH fell below 10.0, it would continue to fall to between 6 and 8; pH levels between 7-10 could not be effectively controlled.

After the seventh week of campaign, cold weather necessitated the use of heated flume water (as indicated by rising pond temperatures), and it was found that adding heat to the system made high pH levels impossible to maintain. In fact during the 10th week of operation 1000 lbs of lime per hour could not reestablish a pH level above 8.0.

It was also found that when pH levels were greater than 10.0 dissolved oxygen was maintained in the system which was not true when levels were below 10.0. (See Figure 4). This was indicated by the fact that dissolved oxygen was carried completely through the ponding system only when the pH of the second pond effluent was greater than 10.0.

Mud Settling, During Campaign

The primary function of the first settling pond was to remove the majority of the suspended solids from the flume water. Almost 98,000 pounds of total solids (including suspended and dissolved solids) were settled each day (See Table 1). The settled mud averaged a moisture content of 83 percent. The fluid nature of the mud made its removal from the settling ponds very difficult.

More than 3 percent of the mud was carbonaceous in nature, and probably was susceptible to biodegradation. Very foul odors were released from the mud, while it was being removed from the ponds, indicating that it was very septic.

Although the settling efficiency of the system was good, the small particle suspended solids seemed to remain in suspension and carry through the system (See Figure 5) as the suspended solids concentration at the second pond effluent increased with continued recirculation.

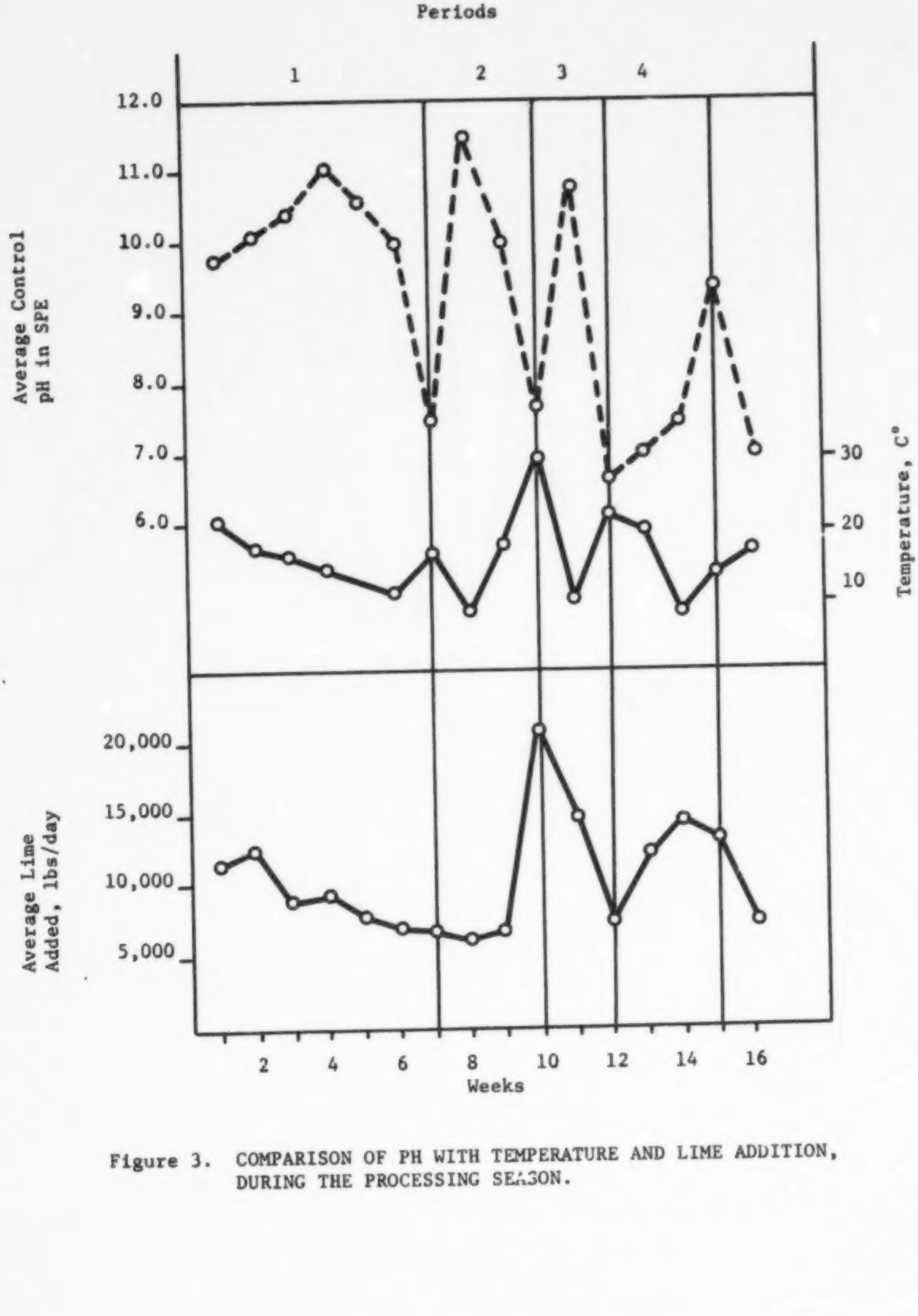

Figure 3. COMPARISON OF PH WITH TEMPERATURE AND LIME ADDITION, DURING THE PROCESSING SEASON.

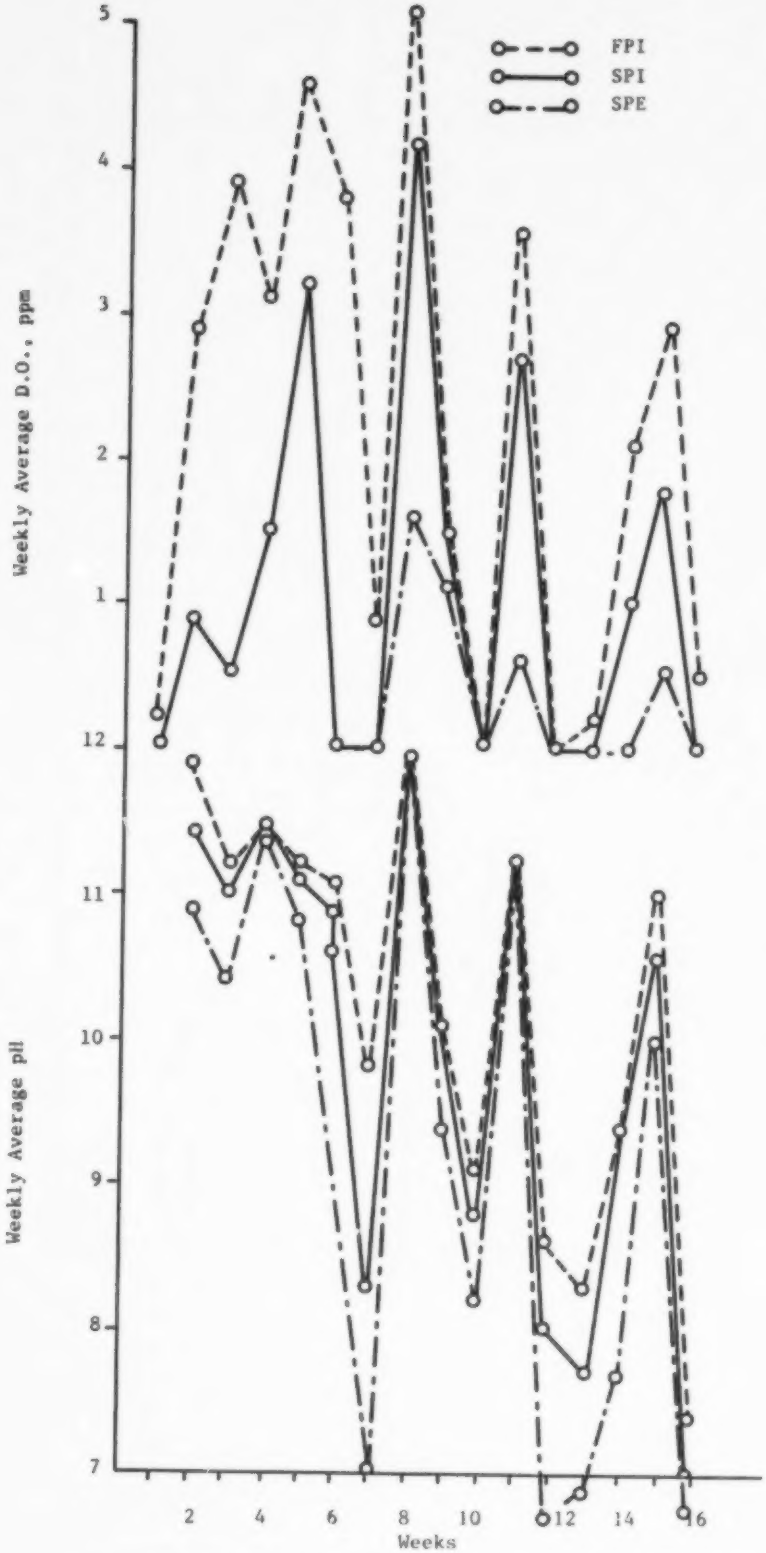

Figure 4. COMPARISON BETWEEN PH AND DISSOLVED OXYGEN AT THREE SYSTEM LOCATIONS, DURING THE PROCESSING SEASON.

TABLE 1. - Weekly mud composites 1968-69 campaign average.

		% on Total Solids	Average Pounds Per Day
Relative Density[1] wet, g/ml	1.366		
Absolute Density g/ml[2]	2.59		
pH[3]	8.6		
Total CaO		6.36	6,220
Soluble CaO		1.25	1,222
Alkalinity as CaO		0.16	156
Dissolved Solids		12.89	12,606
Suspended Solids		87.11	85,190
Total Solids		100.0	97,796
Total Carbon		3.25	3,178

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[1] Relative Density based on maximum compacted volume.

[2] Calculated from Relative Density and percent moisture.

[3] pH was taken on mud diluted to a particular volume, usually 500 ml.

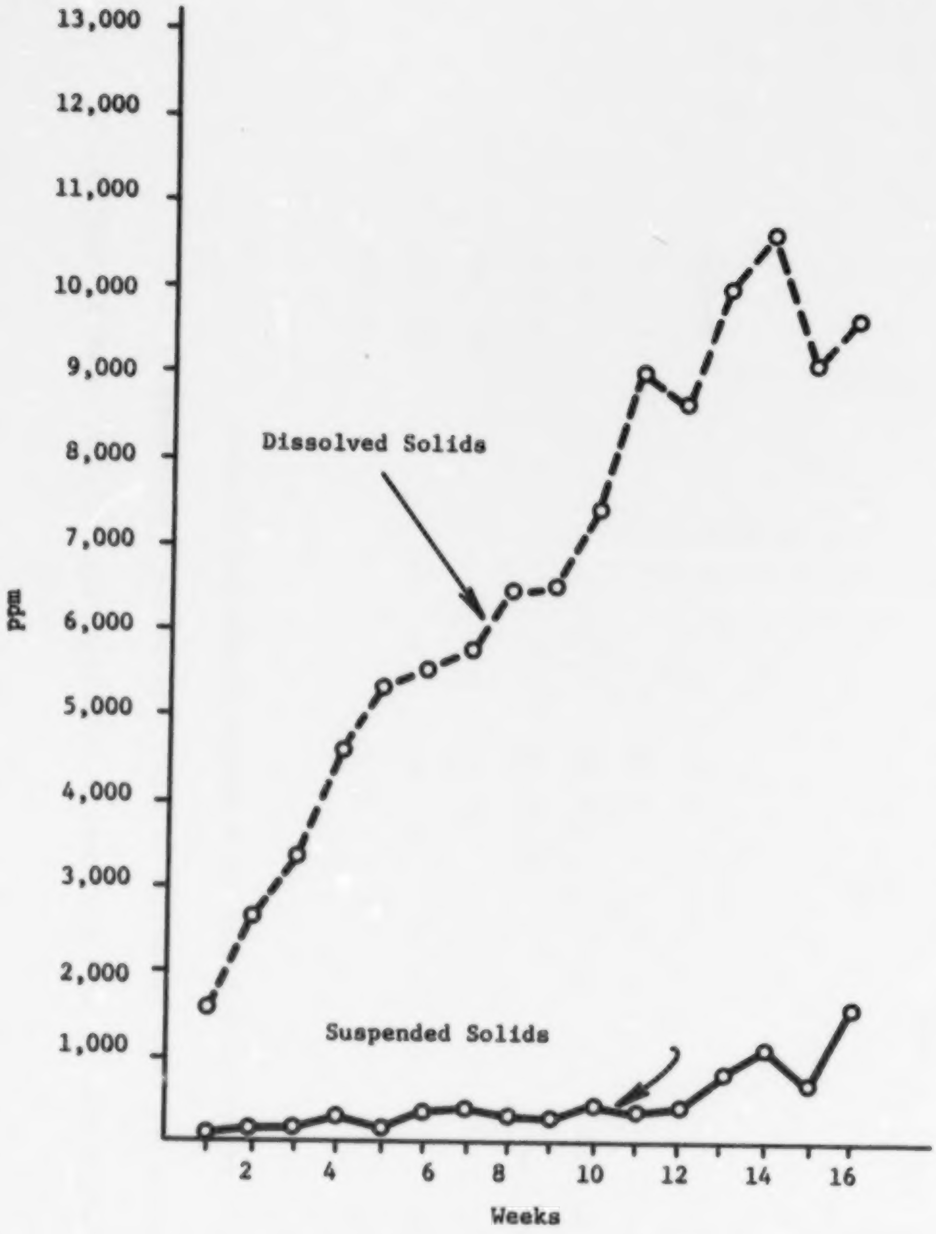

Figure 5. ACCUMULATION RATE OF DISSOLVED AND SUSPENDED SOLIDS, DURING THE PROCESSING SEASON

In the recirculating flume water much of the pollutant load was removed by combined settling and biological activity. A proportion carried through and built up increasing concentrations with continued reuse.

Build-up of Unsettled Solids, During Campaign

As much as 75 percent of the entering BOD was removed and almost 68 percent of the COD was removed. About 75 percent of the total carbon was removed in the ponds and about 80 percent of the total CaO added to the system was removed by the ponds (Table 2).

The build-up of residual solids in the system produced a peak BOD concentration of more than 6000 ppm (See Figure 6). The COD reached a peak concentration of more than 10,000 ppm and the total carbon concentration rose to over 3,000 ppm. The dissolved solids concentration also reached a peak of greater than 10,000 ppm (See Figure 5).

The amount of total sugar in the system was dependent upon the pH (See Figure 7). When the pH was maintained above 10.0 the sugar concentration increased with the time. When the pH fell under 10.0 the sugar concentration decreased and the organic acid concentration increased. This was probably due to the influence of pH upon the bacteria in the ponds. Apparently pH levels above 10.0 seriously inhibit bacterial activity and acid production, but allow sugar to build up in the system.

Generally speaking, high pond temperatures and low pH seemed to be the best environment for high bioactivity, but the data are not clear in many instances. The fact that the total aerobic count was almost always approximately equal to the total anaerobic count indicated that the bacteria were facultative in nature. (Bio-analyses were performed by the Department of Microbiology at Colorado State University).

Post Processing Season Treatment of Water

After the end of the beet processing season, the flume water was discharged to a 1.8 surface acre x 15 ft deep anaerobic pond with two floating 5-HP aerators. The water was held for a period of 31 weeks at which time the quality met discharge standards.

The changes in concentration of the constituents in the residue water selected for analyses are shown in Figures 8 and 9. Note that the pH of the water slowly rose from about 7 to slightly greater than 8. The nitrate and nitrite concentrations consistently remained below the 0.3 ppm level.

Table 2. Analyzed substances[1] entering and leaving the first and second ponds in series, showing percentage removed by the ponds in pounus per ton of beets sliced, 1968-69 campaign average.

Analyses	Pounds, Per Ton of Beets, Entering First Pond	Reduction (or increase) across both Ponds	Pounds, Per Ton of Beets, residual in pounds	% Reduction
BOD_5	2.76	-2.08[2]	0.68	75.4
COD	2.77	-1.74	1.03	62.8
Soluble CaO	0.61	-0.34	0.27	55.7
Total CaO	1.40	-1.12	0.28	80.0
Dissolved Solids	3.13	-1.68	1.45	53.7
Total Carbon	2.03	-1.53	0.50	75.4
Total Sugar[3]	2.24	-1.93	0.31	86.2
Total Acids[4] (As CaO)	--	+0.31	0.42	--
Organic Acids[4] (As CaO)	--	+0.59	0.52	--

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[1] Calculated on static pond volume basis and as if no physical loss and subsequent dilution occurred.

[2] Minus sign designates reduction, plus sign designates increase.

[3] Calculated using periods characterized by high pond pH, where sugar concentration showed a tendency to increase.

[4] Increase across ponds approximately equal to residual in ponds, so no reduction occurred.

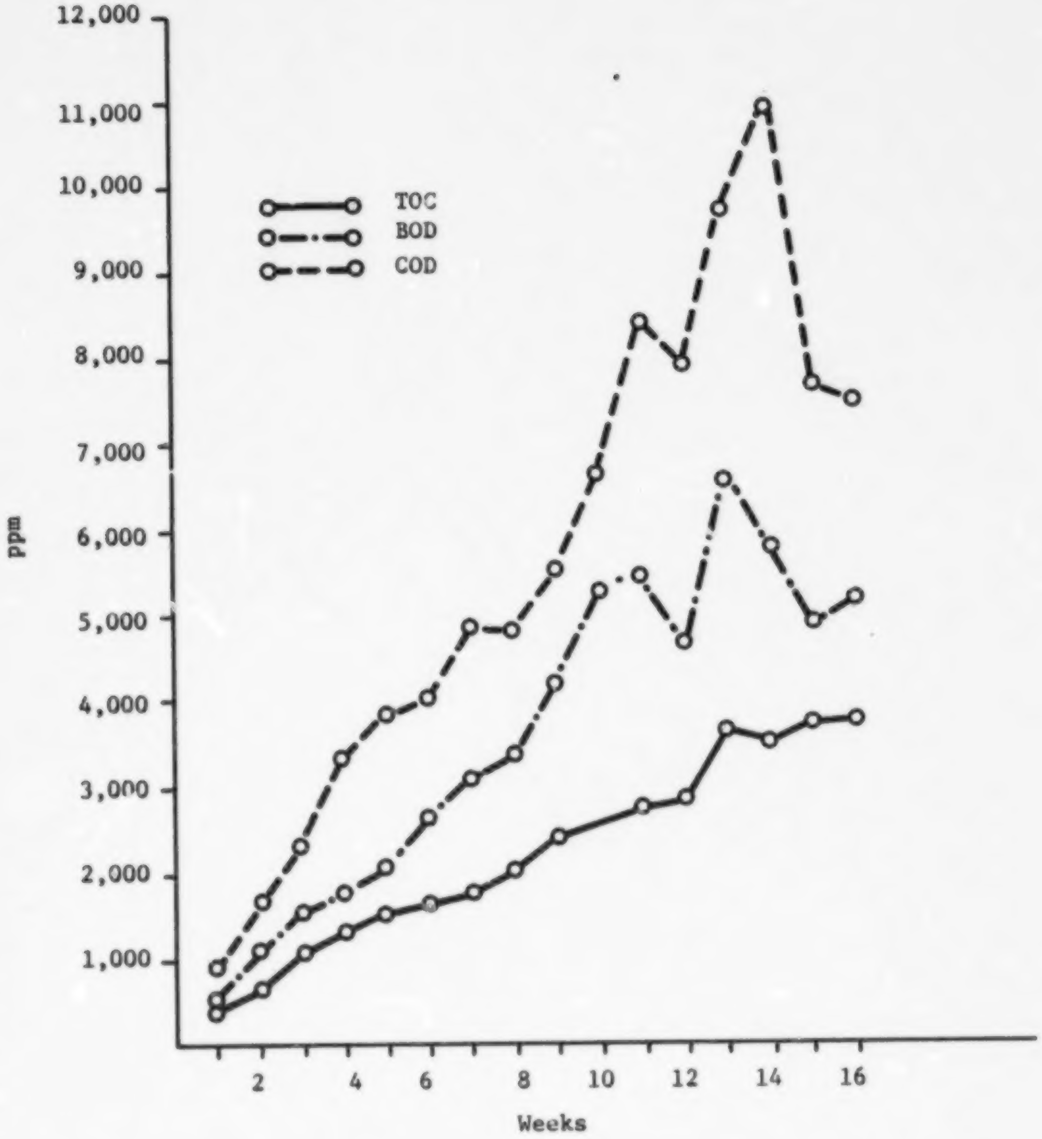

Figure 6. ACCUMULATION RATE OF BOD, COD AND TOTAL ORGANIC CARBON, DURING THE PROCESSING SEASON

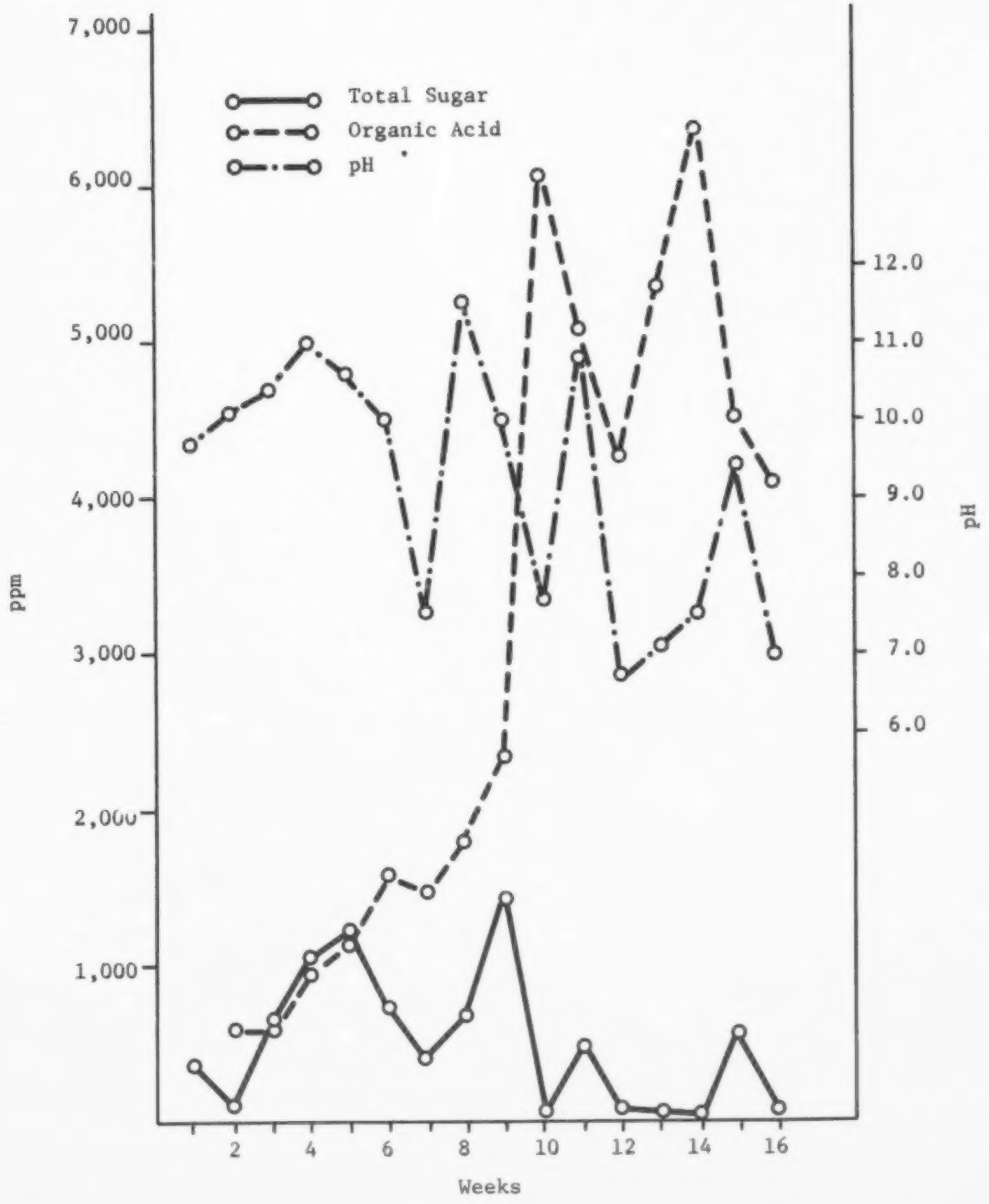

Figure 7. COMPARISON OF PH WITH TOTAL SUGAR AND ORGANIC ACIDS, DURING THE PROCESSING SEASON

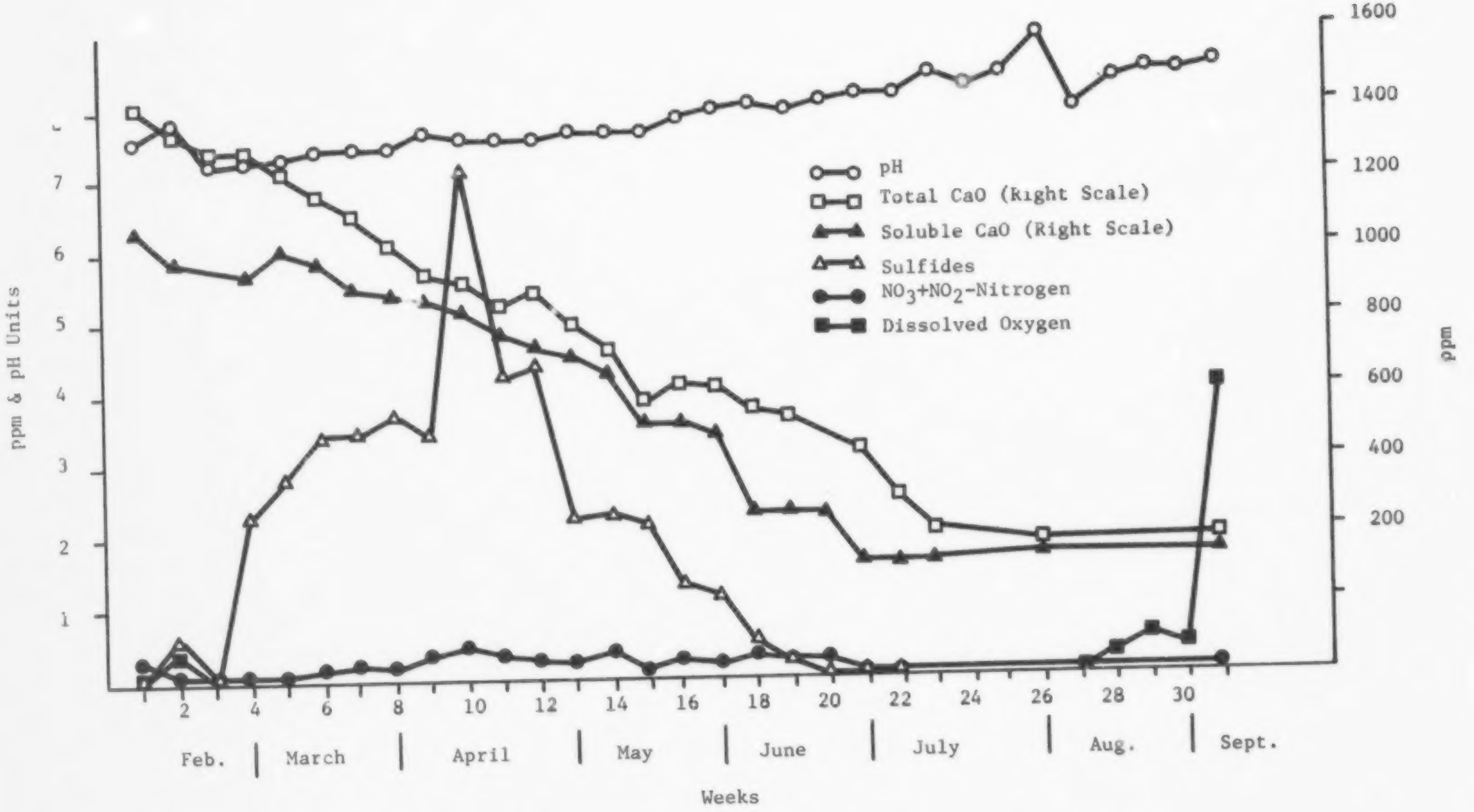

Figure 8. CONCENTRATION CHANGES IN SELECTED CONSTITUENTS, POST-PROCESSING SEASON

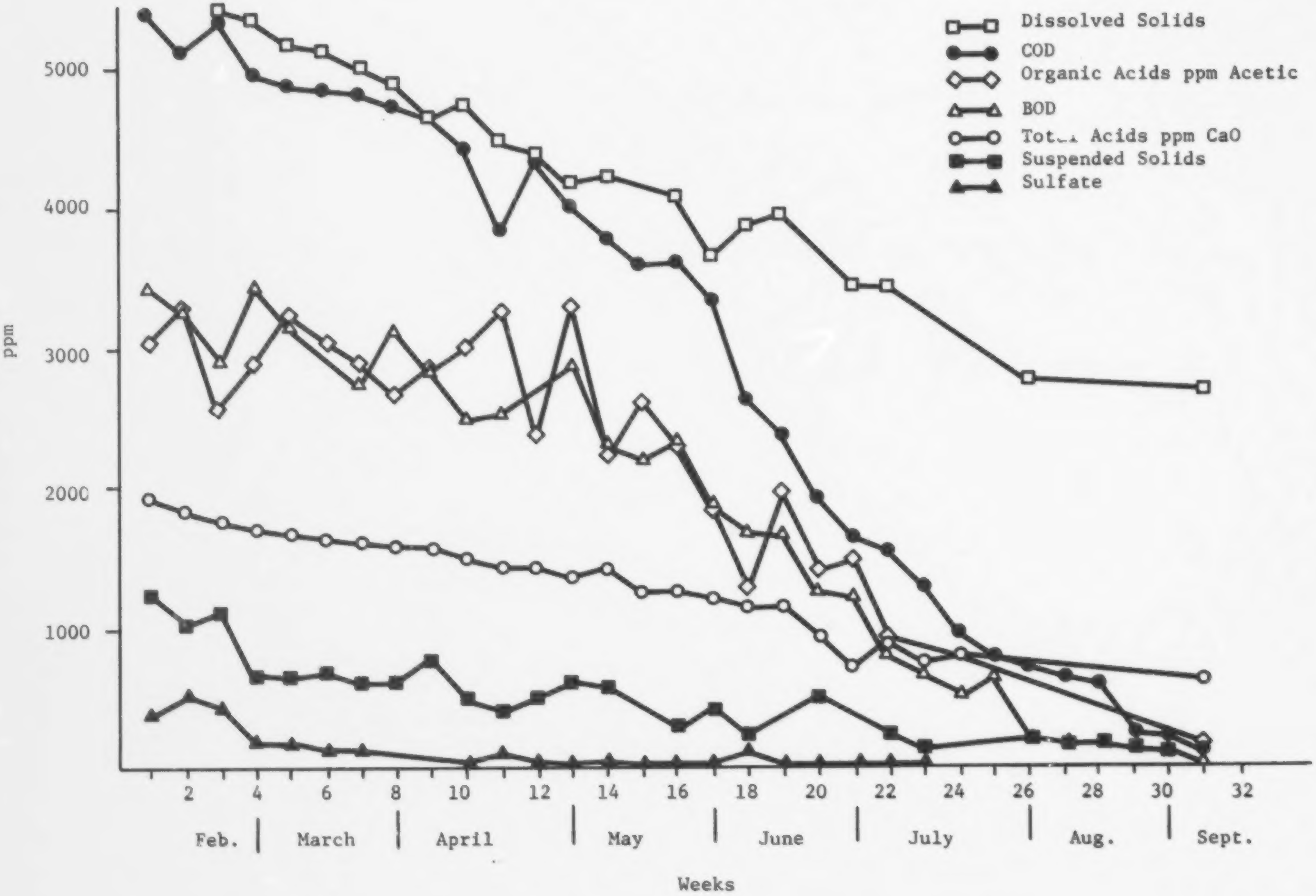

Figure 9. CONCENTRATION CHANGES IN SELECTED CONSTITUENTS, POST-PROCESSING SEASON.

The sulfide concentrations steadily increased to a peak during the 9th week. It was noted that the highest detection of odor was recorded during this same period of time. The increase in sulfides was inversely associated with sulfate until sulfate had essentially dissipated. However, the slow decrease of sulfides after peaking (even with the aerators in operation) would cause one to postulate that organically-bound sulfide was being released.

Dissolved oxygen appeared during the 27th week. At this point the BOD was less than 100 and green algae became evident. Within the next 4 weeks, D.O. had increased to an average of 4 ppm and BOD has been reduced to 31 ppm.

It is of interest to note that the post-campaign pond in which the water was treated was expected to be anaerobic. Theoretically, two 5-HP floating surface aerators were to keep some entrained oxygen in the top layer of the 15-ft deep pond, thus an aerobic layer. The deeper portions of the pond were expected to be anaerobic.

The biological data revealed that the pond existed continually in a biologically falcultative state as stratified anaerobic counts were the same as the aerobic counts. Biological examination also revealed that the prevalent organism was of the genus leuconostoc; leuconostoc is a facultative organism.

The nutrient analyses revealed that very little phosphate was available (See Figure 10). In an attempt to increase the rate of biodegradation phosphate was added to the pond six times during the retention period. The first two times a dry fertilizer was used with the results being only partially satisfactory, since the formulation did not completely dissolve. The last four times, liquid ammonium phosphate was used with the results being fully satisfactory as shown by analysis. Each time phosphate was added the BOD degradation rate increased which indicated that additional phosphate was required.

Note that after each phosphate addition the phosphate was quickly utilized with the exception of after the last addition whereupon the phosphate concentration remained consistent. Since phosphate limits in discharge waters have been established for most states, phosphate must be added carefully towards the end of the holding period if the water is to be discharged. As expected temperature also appeared to effect the rate of biodegradation. Temperatures above 15°C. seemed to produce a faster rate of activity than did temperatures below 15°C.

All of the data collected were statistically treated and computer print out curves were produced. An attempt was made to develop nomographs whereby COD data could be reliably used to predict BOD. Converted COD values were established as adequate for internal control, but not accurate enough for the reporting to regulatory branches of the State and Federal Governments.

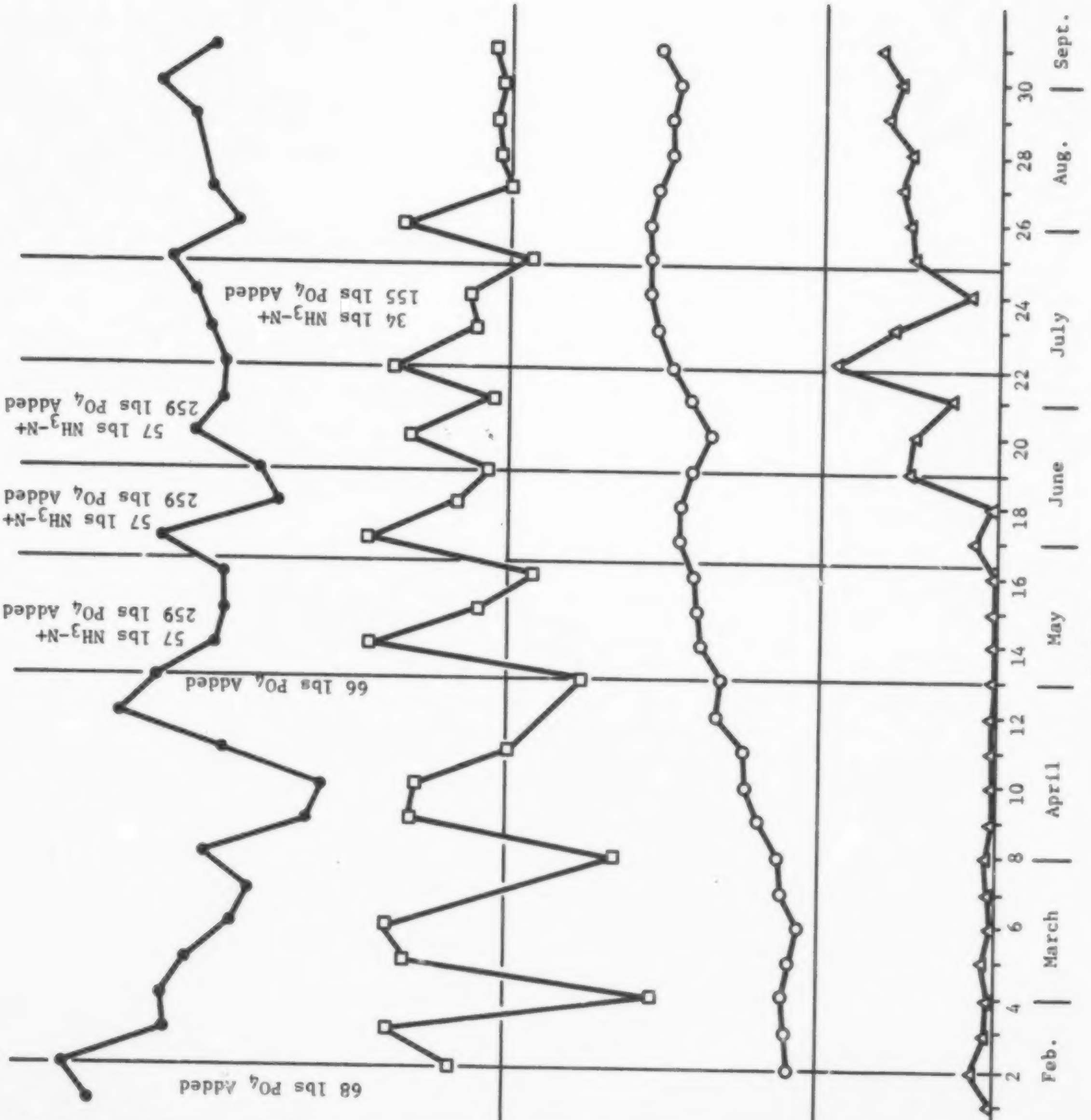

Figure 10. EFFECTS OF NUTRIENTS AND TEMPERATURE ON RATE OF BOD REMOVAL

It became evident from all the data, that if the impounded water was of high enough quality for discharge, there was no valid reason to release it. As a result the water from the first year of operation was used to fill the fluming system the second year and was again used for the same purpose during the 1969-70 processing season. With the exception of a planned discharge from the deep pond during the first year, none of the flume water has been discharged to a nearby stream. From this standpoint the results have exceeded the initial expectations.

SUMMARY AND CONCLUSIONS

Considerable progress has been made by the U. S. beet sugar industry during the past several decades in reducing the discharge of suspended and dissolved solids to receiving water bodies. A two year study on the containment, treatment, recirculation and reuse of sugarbeet fluming and wash water is reported.

Settleable solids were concentrated into a sludge (mud) by continuous addition of a slaked lime slurry. Two alternately-used first settling ponds in series with a second pond removed an average of 75 percent of the BOD and 54 percent of the dissolved solids. When pH exceeded 10.0, greater than 90 percent of the settleable solids were removed before water returned to the fluming and washing operation. BOD, COD and total dissolved solids continued to increase during the operating campaign. With a water temperature rise above 20°C., pH dropped and could not be recovered with large quantities of lime addition.

At the end of a 16-week processing campaign, the system and surplus waters were discharged into a 1.8 surface acres by 15 ft. deep pond with two 5-HP surface aerators. The initial 3000 ppm BOD, 6000 ppm dissolved solids water was degraded to less than 50 BOD, 4 ppm D. O. The expected anaerobic processes proved to be facultative prolonging the period of digestion to 31 weeks. The prevalent organism was leuconostoc. Odor initially was very slight, rose to a peak in about 9 weeks and declined to a negligible degree 8 weeks later. Odor was associated with the analyses for sulfides. The rate of degradation was enhanced by the periodic addition of liquid ammonium phosphate. The ponded water was not discharged but was used to fill the fluming-washing system for the next processing season.

Sugarbeet flume water can be recirculated without odor provided the water temperature and pH can be controlled. Settleable solids can be removed by ponding or by mechanical clarifiers. Non-odorous treatment of the settled mud remains an unsolved problem. The control of odors during peak activity during post campaign treatment of residue water remains unsolved.

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RECONDITIONING AND REUSE OF OLIVE PROCESSING BRINES

by

Walter A. Mercer, Harry J. Maagdenberg, and Jack W. Ralls*

The preservation of olives in California is a small industry with a wholesale product value of approximately $40,000,000 annually. The preparation of olives for canning creates a strong liquid waste which is high in both BOD and sodium chloride content. Since the latter material is not biodegradable, discharges from olive canning plants have the potential for saline pollution of receiving waters.

The industry receives about 50,000 tons of olives for preservation during mid-September to mid-November of each year. A portion of the freshly harvested olives are treated with lye, aerated and washed for black, ripe olive production (so called fresh-curing). The bulk of the freshly harvested olives are put in storage using 3-4 percent sodium chloride solutions; these are increased in concentration to 6-8 percent over a period of 4-10 weeks. Olives from brine storage are taken for preparation of canned, black ripe olives over a period of 6-11 months, depending on the production schedule of the individual cannery.

The purpose of the project being described in this paper was the reconditioning of spent olive storage brines on a commercial scale and evaluation of their reuse potential. The technology under investigation was based on exploratory work done at the Albany (California) Laboratory of the USDA where olive brines were upgraded using activated carbon treatment.

A pilot-plant-scale, brine, reconditioning unit was constructed and used at four olive canneries in the Central Valley of California. A schematic of the brine reconditioning unit is shown on Figure 1. Figures 2 to 4 show photographs of the brine reconditioning unit on site at an olive cannery.

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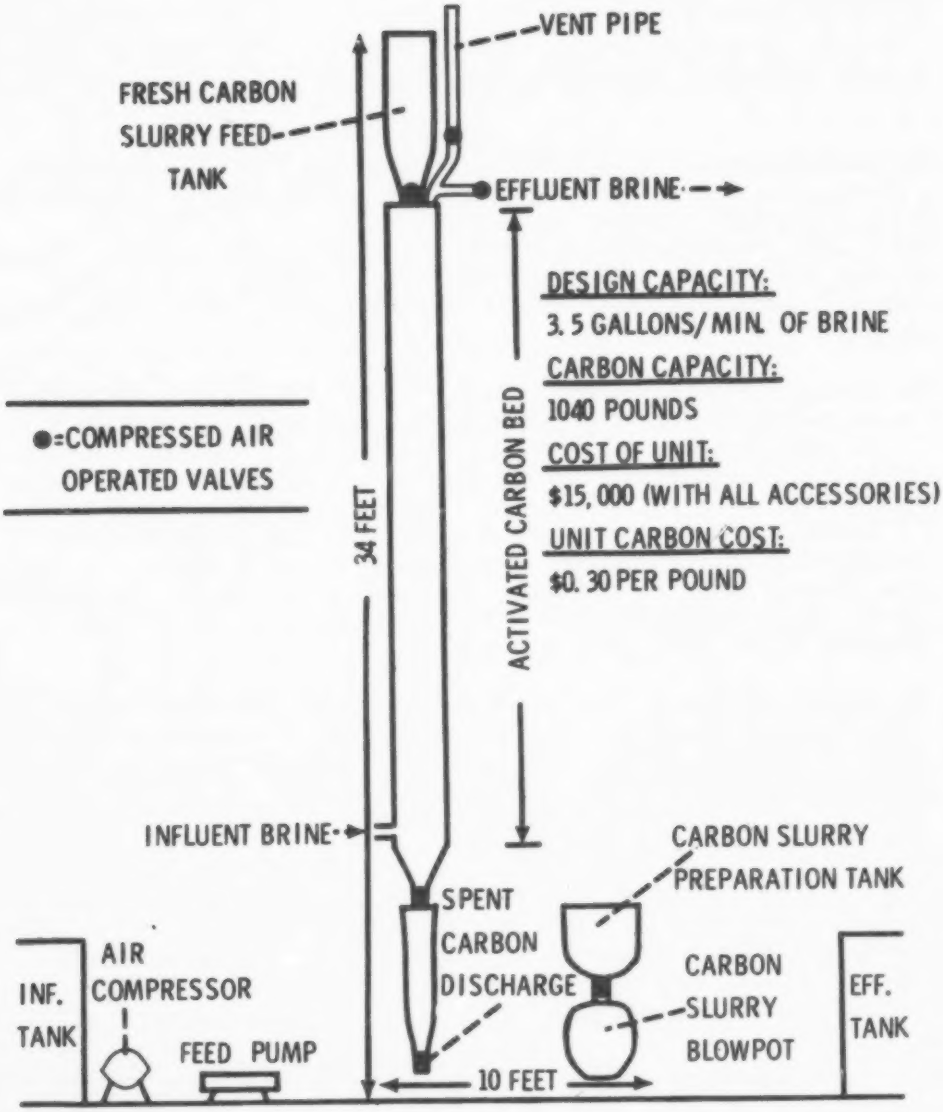
VENT PIPE
FRESH CARBON SLURRY FEED TANK
EFFLUENT BRINE
DESIGN CAPACITY:
3.5 GALLONS/MIN. OF BRINE
CARBON CAPACITY:
1040 POUNDS
COST OF UNIT:
$15,000 (WITH ALL ACCESSORIES)
UNIT CARBON COST:
$0.30 PER POUND
●=COMPRESSED AIR OPERATED VALVES
34 FEET
ACTIVATED CARBON BED
INFLUENT BRINE
SPENT CARBON DISCHARGE
CARBON SLURRY PREPARATION TANK
CARBON SLURRY BLOWPOT
INF. TANK
AIR COMPRESSOR
FEED PUMP
10 FEET
EFF. TANK

Figure 1. SCHEMATIC OF BRINE RECONDITIONING UNIT

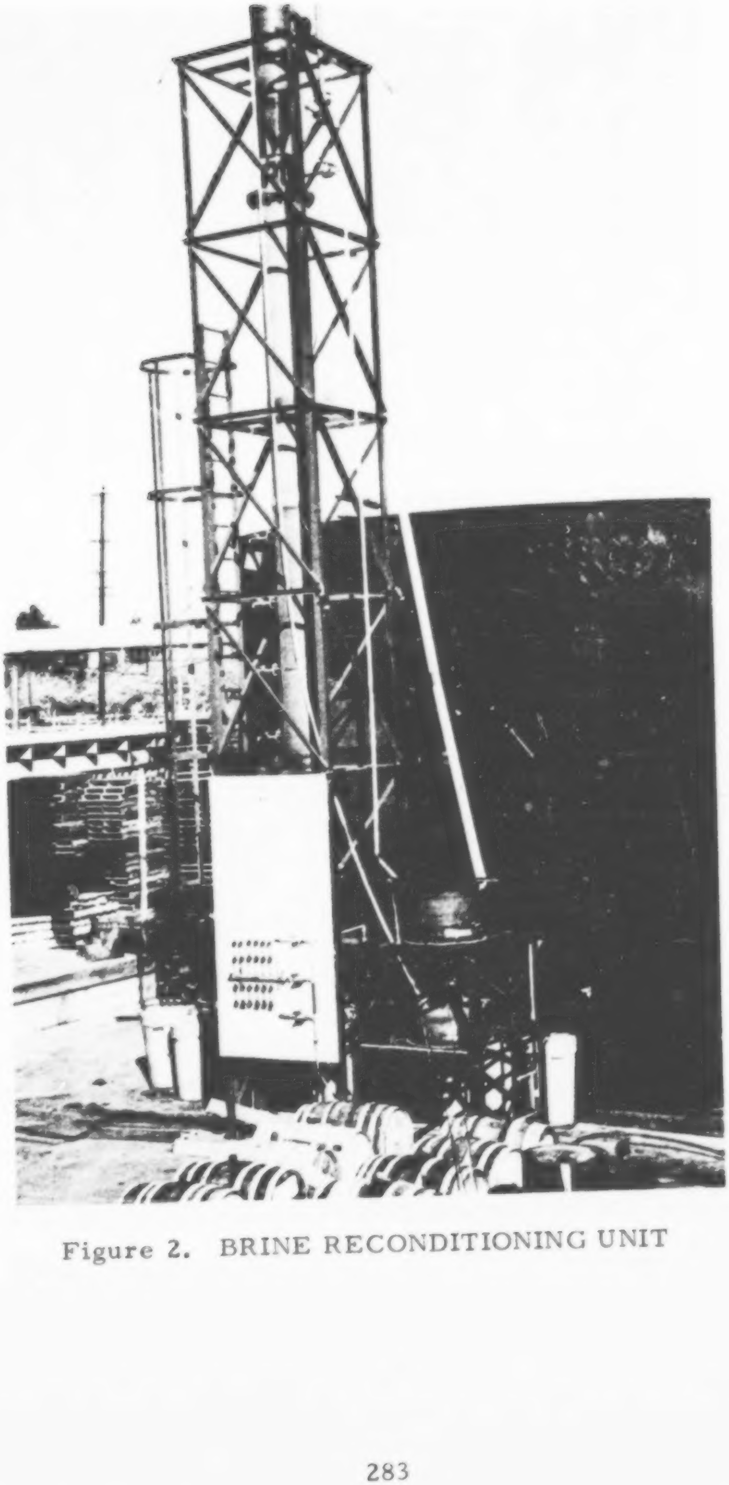

Figure 2. BRINE RECONDITIONING UNIT

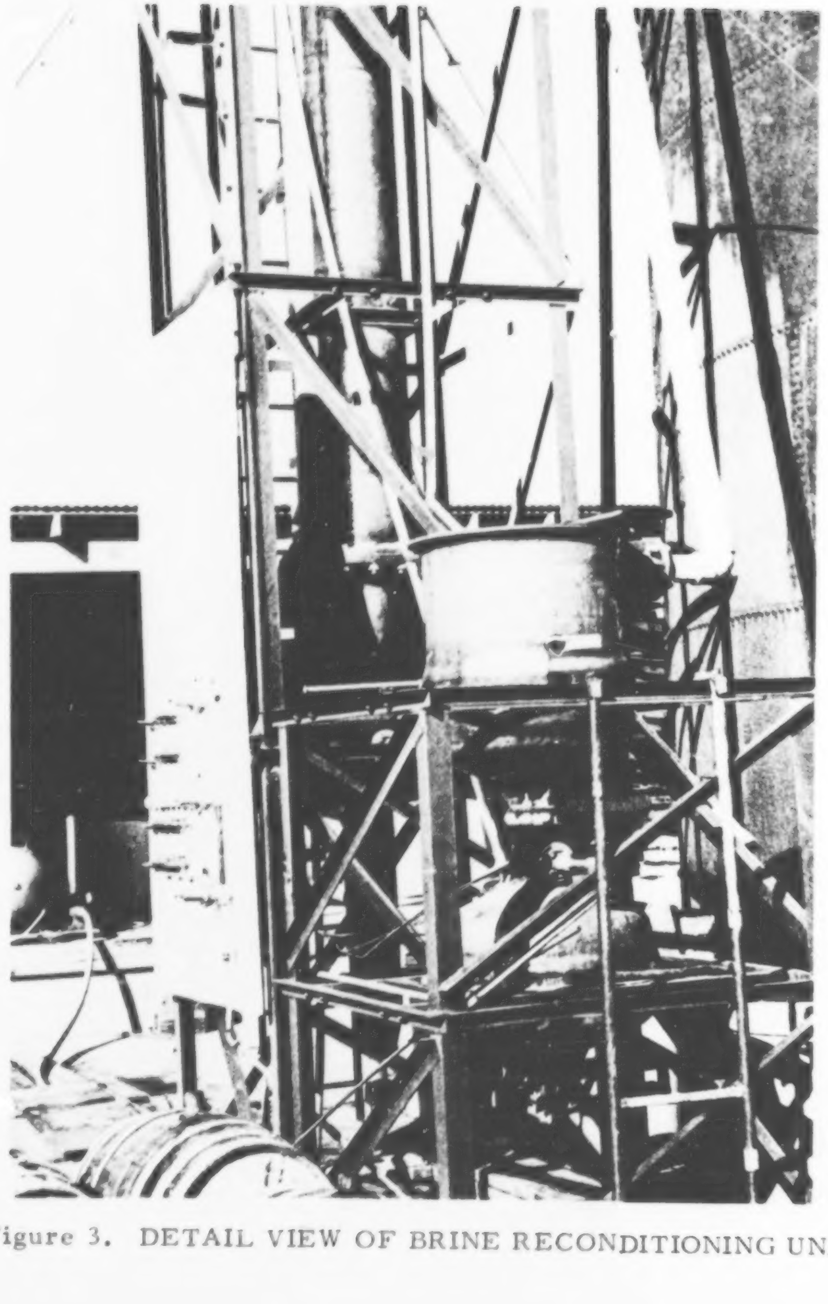

Figure 3. DETAIL VIEW OF BRINE RECONDITIONING UNIT

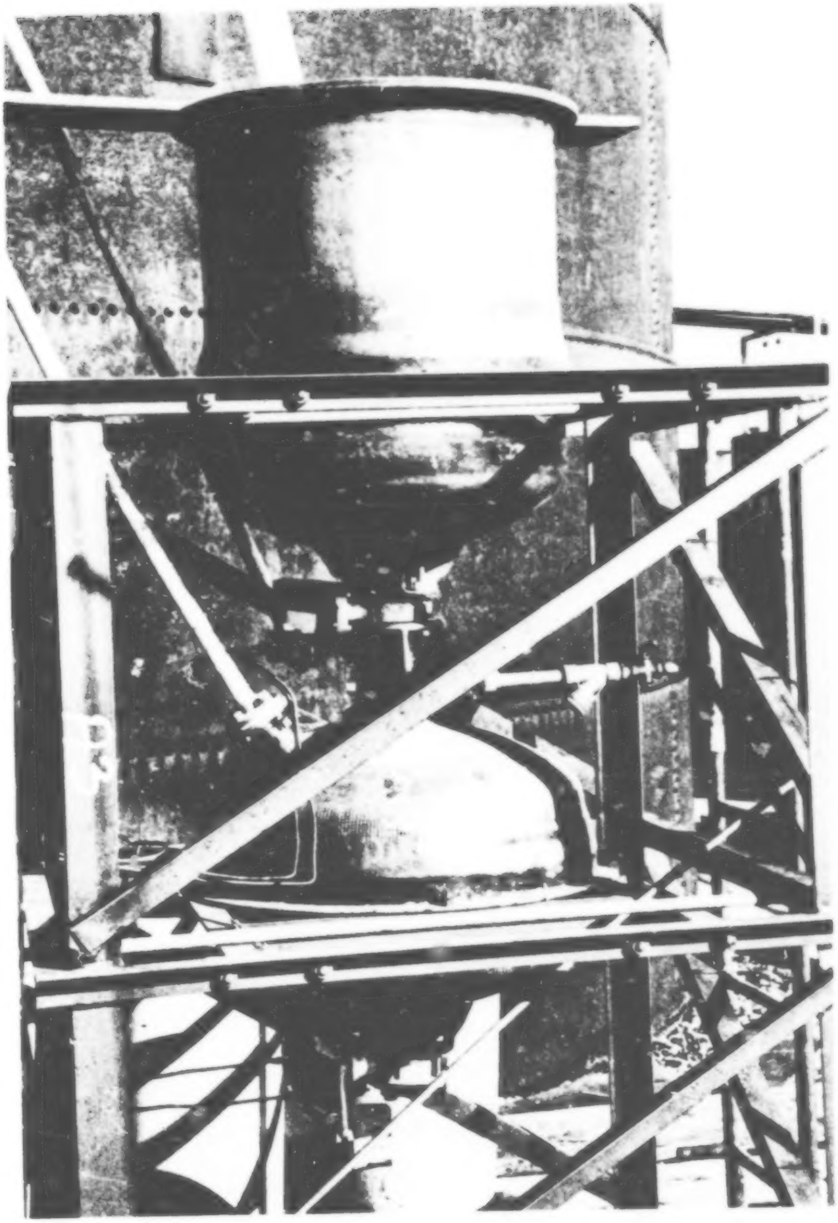

Figure 4. BLOWPOT AND CONTROL PANEL

At each of the four locations, substantial volumes of spent storage brine were put through the carbon column. The influent feed rate was varied from 0.5 to 3.5 gallons per minute. This flow rate corresponded to 0.36 to 2.5 gallons per minute per square foot of carbon area. The extent of treatment of the brine was followed by measuring COD, suspended solids, pH, total acidity and color (transmittance at 425 millimicrons).

The results of a series of analyses made on brine samples are illustrated on Figures 5 to 9. The data indicate the surges which were always observed when the brine contacted fresh carbon. In the figures showing changes in pH, total acidity and COD, there were six additions of 60 pound portions of fresh carbon, and a significant change was noted in the analytical measurements determined immediately after each addition of carbon.

The measurement of light transmittance followed a consistent pattern (Figure 7). The effluent was essentially transparent to light of 425 millimicrons wavelength until approximately 6,000 gallons of brine had contacted a single charge of 1000 pounds of activated carbon; the transmittance then decreased with increasing effluent gallonage to a value of about 75 percent at 10,000 gallons of collected effluent. The suspended solids content followed no definite pattern in one series of samples. In general, the suspended solids content decreased due to the carbon bed acting as a filter, but the inconsistent generation of carbon fines from loading of carbon slurry and abrasion gave a random pattern to the results. The fluctuations in values on fresh carbon addition were of short time duration and typical values for composited effluents are tabulated in Table 1. These results show that carbon treatment significantly reduced COD and color, but had little effect on pH, total acidity, salt content, and suspended solids content.

A secondary disposal problem in olive canning plants is caused by the large volume, low salt strength, processing waters. Two types of processing waters were treated with activated carbon with the results shown in Table 2. For the lye rinse water and transport brine, there were substantial reductions in suspended solids (apparently due to larger particle size compared to storage brines) and COD. These treated rinse waters were reused in commercial production with no detectable effect on the quality of the canned olives as judged by production personnel. There is considerable promise of using carbon treatment of processing waters to recondition these liquid wastes for reuse at considerable saving in potable water and reduction of saline pollution potential.

The project plan included storage experiments of freshly harvested olives in carbon treated brine. The success of the storage was judged by the quality of the final canned product as determined by a taste panel.

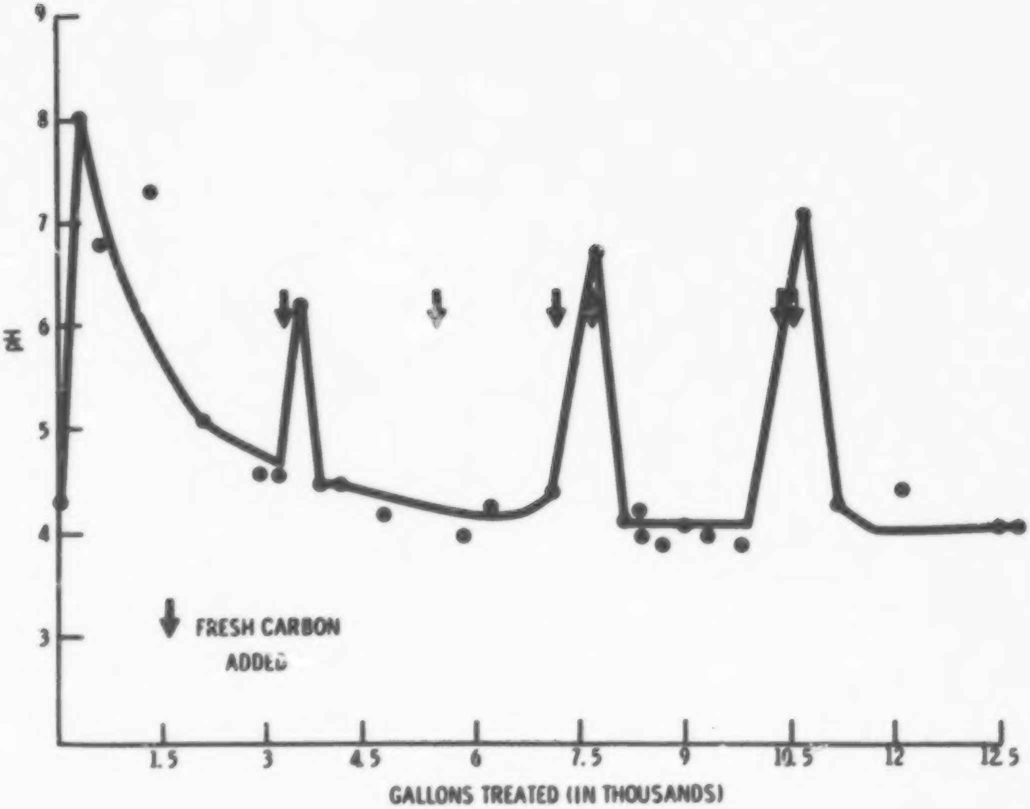

Figure 5. pH OF RECONDITIONED LINDSAY STORAGE BRINE

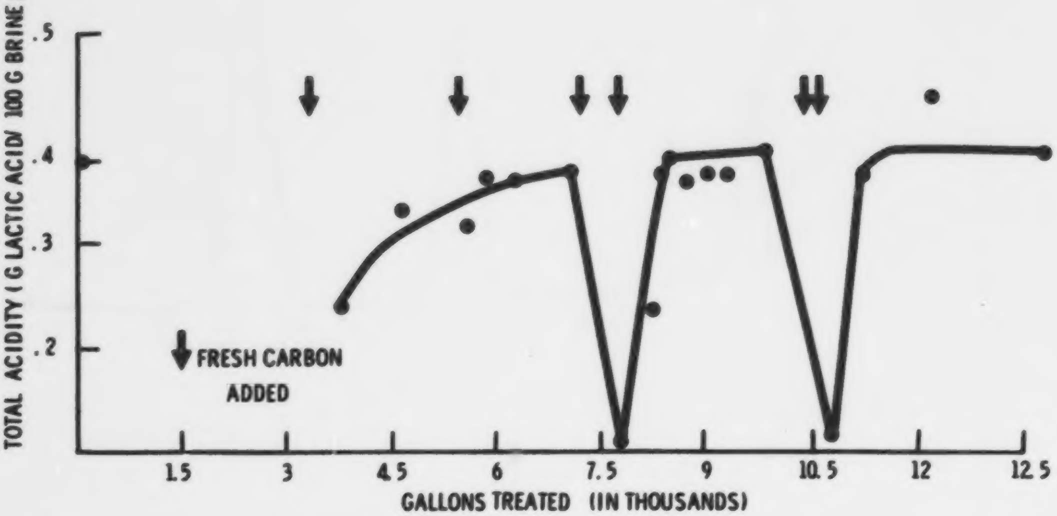

Figure 6. TOTAL ACIDITY OF RECONDITIONED LINDSAY STORAGE BRINE

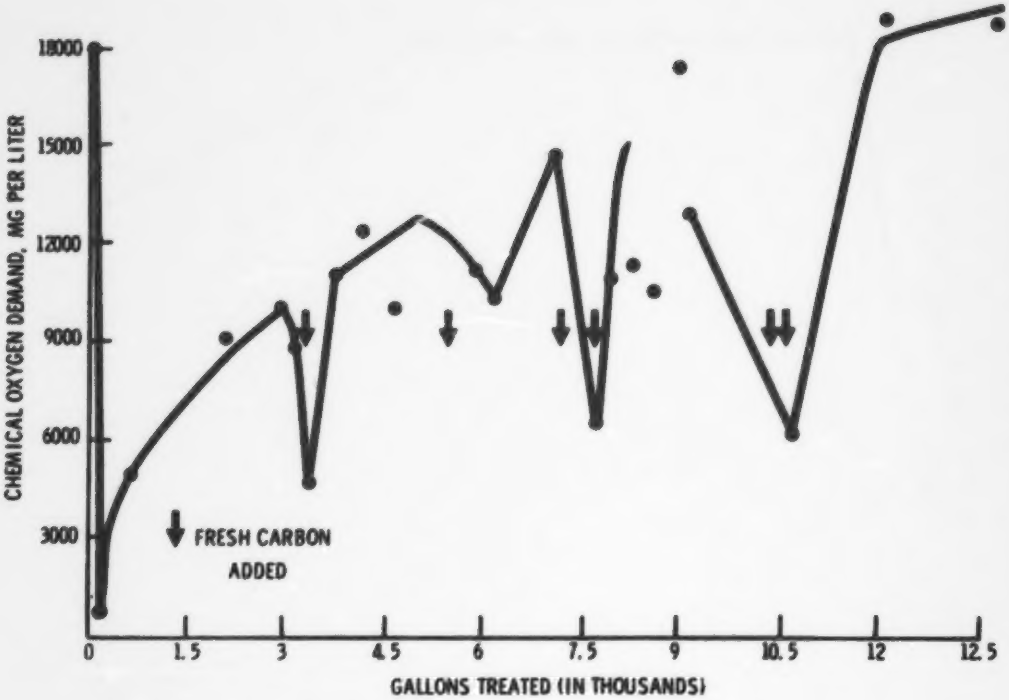

Figure 7. CHEMICAL OXYGEN DEMAND OF RECONDITIONED LINDSAY STORAGE BRINE

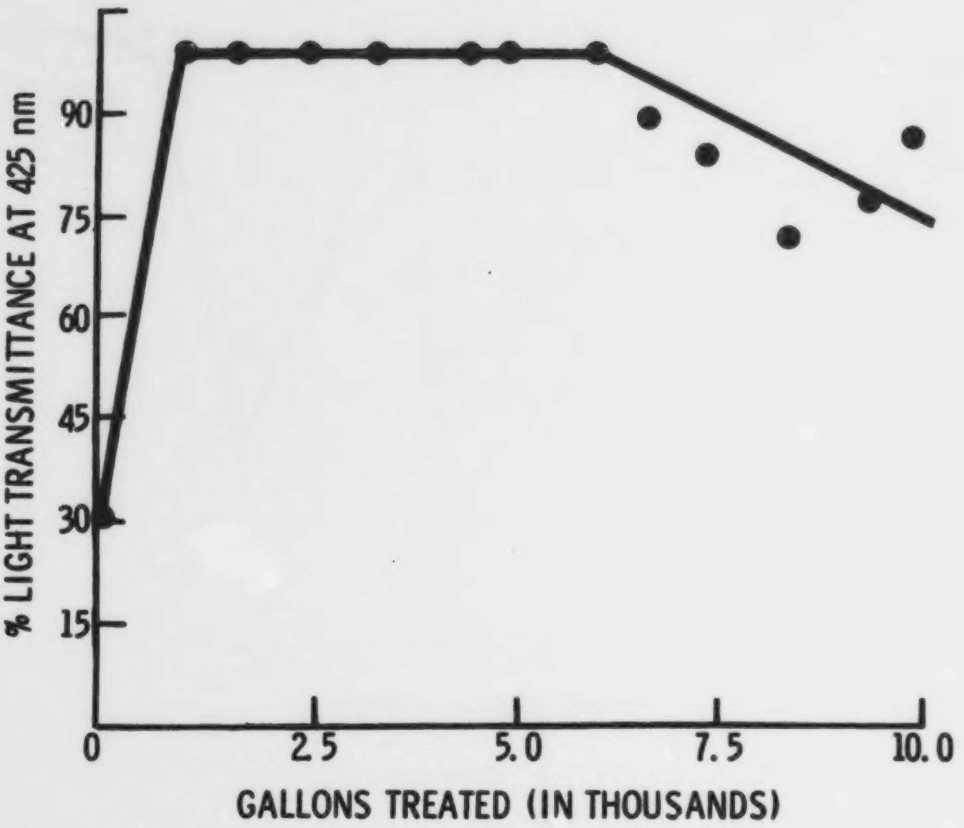

Figure 8. COLOR INDEX OF RECONDITIONED VISALIA STORAGE BRINES

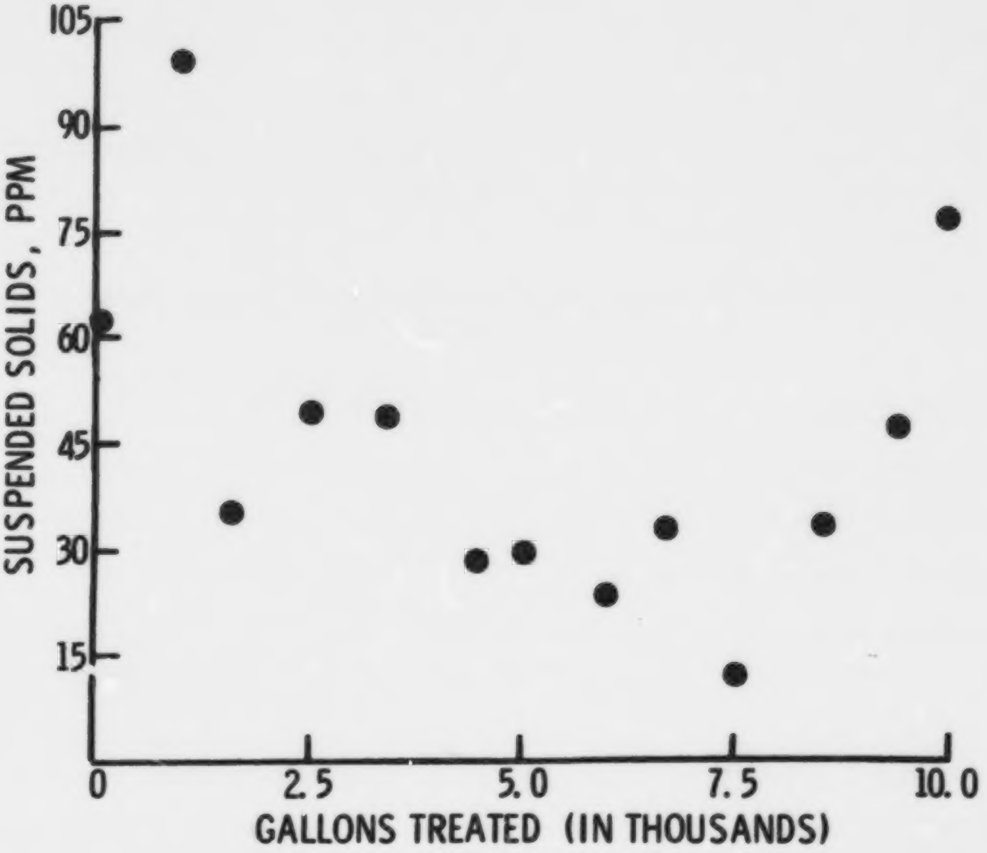

Figure 9. SUSPENDED SOLIDS CONTENT OF RECONDITIONED VISALIA STORAGE BRINE

Table 1. Brine Reconditioning

	Influent	Effluent
pH	4.0-4.3	4.2-8.8
Acidity	0.3	0.02-0.39
Color	70.5	75-100
NaCl	5.5	5.2-5.5
SS	200-286	164-220
COD	18,000	5,000-16,500

Table 2. Removal of Suspended Solids and Chemical Oxygen Demand From Brines and Process Waters

	Percent Removal, Average	
Liquid Treated	Suspended Solids	COD
Lye Rinse Water	91	62
Transport Brine	100	25
Domestic Spanish Olive Brine	21	38
Imported Spanish Olive Brine	30	65

Table 3. Quality of Olives Stored In Reconditioned Brine

Extent of Treatment Gallons Brine : Pounds of Carbon	Brine Storage Time, Days	Canned Product Flavor Ranking 1 = Best, 4 = Worst
14 : 1	64	2.13
2 : 1	36	2.85
5 : 1	4	2.62
Similar Commercial Sample		2.39

A 15 ton lot of olives were stored in 1530 gallons of reconditioned brine for several months. A sample of olives stored in this tank was prepared and canned at the six month storage time. A taste panel could not detect any difference between the sample from reconditioned brine storage and a similar sample stored in virgin brine. The olives in the tank of reconditioned brine were used in commercial production and sales with no adverse comment by quality assurance inspection or consumer reaction.

A more extensive testing of reconditioned brine was made during 1969-1970. One hundred pound lots of olives were stored in three types of reconditioned brines having different effluent volume to carbon ratios and different lengths of storage after reconditioning in the absence of olives. After 4.5 months of storage, samples from each of the three types of brine were prepared and canned. A similar sample from virgin brine storage was used as a control. The canned samples were presented to a laboratory taste panel who were asked to rank the samples in order of preference with 1 for the best and 4 for the worst. If the samples were identical in flavor, then each sample would have a ranking number of 2.5 after a number of individual judgements were averaged. The results of this test are summarized in Table 3. The sample from the brine having the highest gallonage to carbon ratio and the longest storage period before olives were introduced has a ranking comparable to the commercial control samples. Actually, all four samples were of good quality and difficult to distinguish from one another.

We conclude from this study that the reconditioning and reuse of olive storage brines is a commercially feasible process. We see two options for use of this carbon treating of brine in the industry. In a first stage, two to four canneries with an urgent need to reduce saline waste liquid discharge would each have a brine reconditioning unit capable of producing in a 12-week period enough brine to store 5,000 tons of freshly harvested olives. No carbon regeneration would be done at this stage. In a second stage, 10 canneries would each have a brine reconditioning unit rated at 5,000 tons of olives storage capacity. A centrally located carbon regeneration unit would be operated cooperatively to regenerate the carbon from all ten plants.

The cost of brine reconditioning would be about $0.50 per ton of olives in the first stage and $1.00 per ton of olives in the second stage, using a 10-year amortization period. Freshly harvested olives average about $300.00 per ton, so the increment in cost due to brine reconditioning is a relatively small figure.

TRICKLING FILTER TREATMENT OF FOOD CANNING WASTE WATERS

by

Walter W. Rose*

INTRODUCTION

The treatment of food canning waste waters, by the trickling filter process, has had a long and varied history. Under optimum conditions, the system has produced satisfactory results. Many investigators including sewage treatment plant operators have, at times, experienced little success with the operation of conventional rock filled filters. I believe some of the reasons rock filters have not been able to provide adequate treatment to food wastes are as follows:

1. Canning operations may, by necessity create a sudden change in the volume of the effluent discharged or a sudden change in the character of the waste. The most common changes are increases in acidity or alkalinity or in the organic load.

2. Related to these changes is the possible stop and go nature of plant operations which is caused by breakdowns or fluctuations in the quantity of incoming raw product.

3. Wastes from fruit canning are deficient in certain nutrients needed in a biological treatment system. Most food wastes are low in nitrogen and possibly phosphorous.

4. Food canning wastes are generally high in carbohydrates and other simple organic compounds. These compounds are readily metabolized by bacteria and as such impose a high immediate oxygen demand on the treatment system.

Points number 1 and 4 create conditions which seriously affect the performance of rock filters.

In recent years significant changes have been made in certain aspects of trickling filter treatment systems. One of the most important changes has been in development of uniform filter media as a substitute for rock. In particular, the development of plastic to replace rock has greatly expanded the potential of using the trickling filter

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process in treating high strength industrial wastes. Much credit for exploring the use of plastic filled trickling filters must go to Dr. Chipperfield in England and Germain in this country.

The National Canners Association began an evaluation of these new filters in 1962. In this paper I will attempt to highlight some of our findings that have been obtained from three different units.

Figure 1 illustrates an important principle which is applicable to any treatment system. Any product whether it be artichoke or zucchini will have certain operations that produce a high strength waste stream. In our surveys we have found that within a plant there may be 2 to 3 waste streams that account for most of the BOD discharged and that the volume of these waste streams will be a low percentage of the total flow. For economical treatment, the strong waste should be segregated from the weaker wastes streams.

Outlined below are four reasons or justifications for conducting research on the use of plastic filled trickling filters.

1. High Concentration of Soluble Solids - Studies have shown that 80 - 90 percent of the BOD is in the soluble form. Compounds in the dissolved state are not readily removed from solution by either physical or chemical means.

2. Necessity for Microbial Removal of Soluble Solids - If physical and chemical methods are not appropriate for the removal of soluble solids, then one must rely on biological methods.

3. Need for High Rate-Space Saving Treatment Method - This is particularly true in urban areas where land costs are high or nearly non-existent as a result of plant expansion over the years.

4. High Organic Loadings and Removals - Past research has indicated that plastic filters are especially adaptable to both of these criteria that are not easily met by other treatment systems.

The following is a list of parameters which we have investigated. The first five items are basic to any biological process. The sixth item is the only one unique to the trickling filter process. It has been necessary for us to evaluate each of the parameters as there was a scarcity of available information related to treatment of food processing wastes using trickling filters.

1. Toxicity - This was not a problem since we were investigating waste from food processing.

2. Nutrients - Bacteria require a balanced diet if they are to be efficient in the removal of BOD.

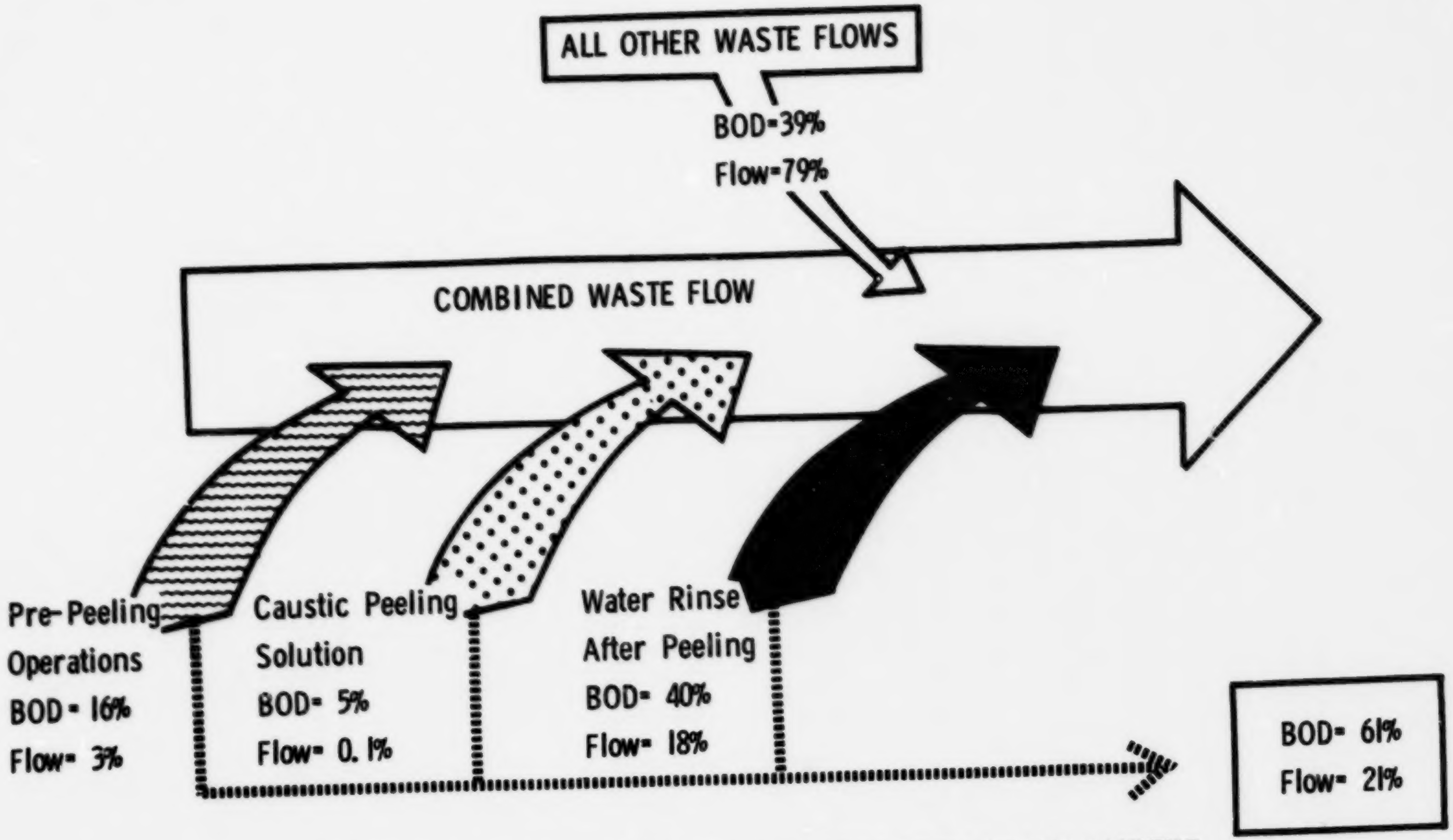
ALL OTHER WASTE FLOWS
BOD-39%
Flow-79%
COMBINED WASTE FLOW
Pre-Peeling
Operations
BOD- 16%
Flow- 3%
Caustic Peeling
Solution
BOD- 5%
Flow- 0.1%
Water Rinse
After Peeling
BOD- 40%
Flow- 18%
BOD- 61%
Flow- 21%

Figure 1. SOURCE AND STRENGTH OF WASTES WATERS FROM PEACH CANNING

3. pH - Must not be too acid or alkaline otherwise performance of the treatment system is adversely affected.

4. Organic Loading - To determine the ability of the filter in accepting high organic loadings.

5. Hydraulic Loading - To determine the reaction of the system to both high and low flow rates.

6. Depth of Packing - To determine the distribution of BOD removals with filter depth for optimum use of the total height.

Figure 2 is a schematic drawing of a pilot scale trickling filter that was used in the initial phases of our investigation. The filter is 34 feet in height and 3 feet in diameter. It is packed to a depth of 21.5 feet with plastic media. The unit contains pumps, rotary distributor, nutrient feed and sample collection equipment.

Separate pumps are used to introduce raw waste and a recycle stream to the top of the filter. A distributor spreads the combined flows over the top of the packing media. Experience has shown that within 3 to 4 days after the start up, the unit is operational.

Figure 3 is a photograph of one bundle or module of plastic media that was used in all three trickling filters. This particular media is manufactured by the Dow Chemical Company and is distributed under the trade name of Surfpac. There are other media of varying design and compositon but we have not had any personal experience with performance from such units.

The plastic media, using a honey comb design, has a high void (94 percent) and a high surface to volume ratic (27 sq. ft. per cubic ft.). The material is polyvinylchloride and is self-supporting to a height of 21.5 feet. The module has nominal measurements of 19-1/2" wide, 39" long and 21.5" in depth.

Listed below are results obtained from the pilot filter. The results are for different products and illustrate that the treatability of each should be considered in designing a treatment system. In obtaining these results, the hydraulic loading remained constant. However, the organic loading was not uniform and must also be considered in designing a treatment system.

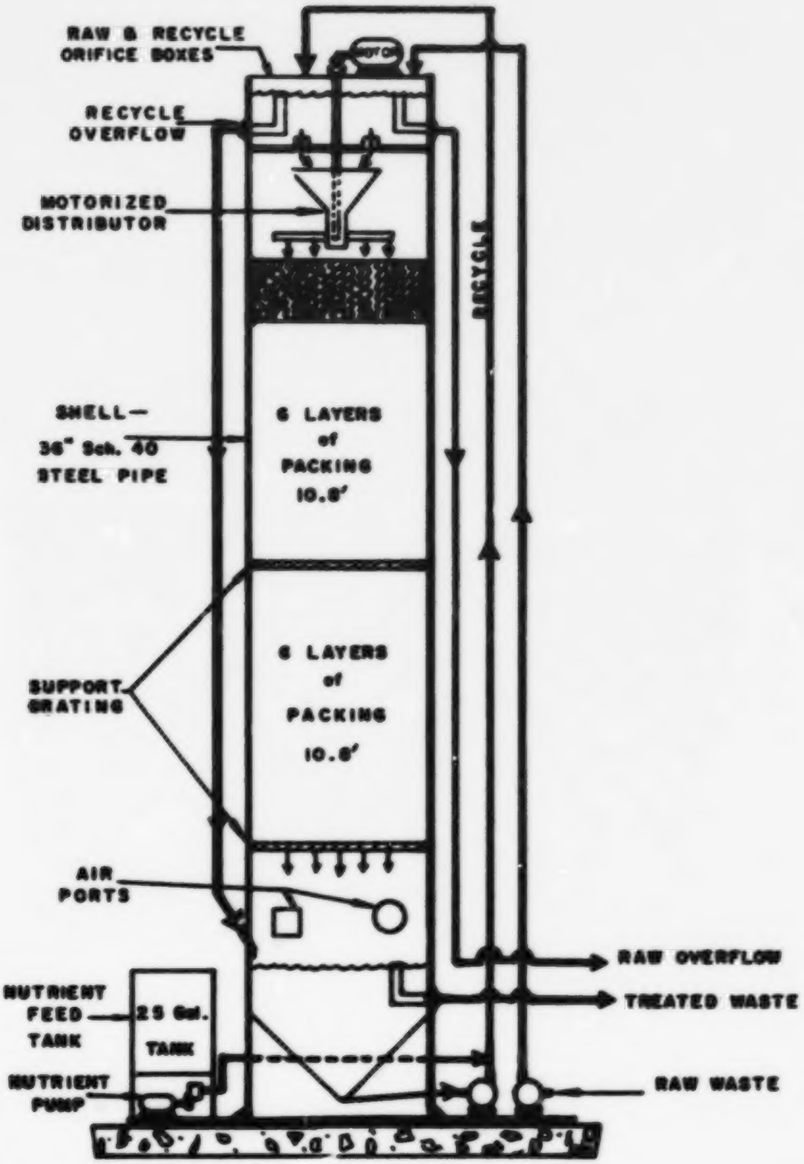
RAW & RECYCLE ORIFICE BOXES
MOTOR
RECYCLE OVERFLOW
MOTORIZED DISTRIBUTOR
RECYCLE
SHELL— 36" Sch. 40 STEEL PIPE
6 LAYERS of PACKING 10.8'
6 LAYERS of PACKING 10.8'
SUPPORT GRATING
AIR PORTS
RAW OVERFLOW
TREATED WASTE
NUTRIENT FEED TANK
25 Gal. TANK
NUTRIENT PUMP
RAW WASTE

Figure 2. SCHEMATIC DIAGRAM OF THE FILTER UNIT SHOWING THE ARRANGEMENT OF THE FEED SYSTEMS AND FILTER LAYERS

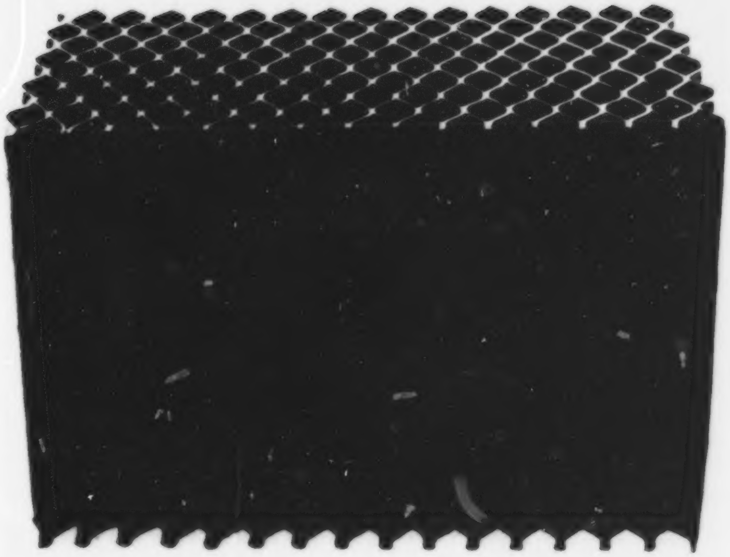

Figure 3. SINGLE BUNDLE OF PACKING MEDIUM.

Table 1. Filter Performance

Product	BOD ppm	Percent Removed
Peas	642	24.7
Peaches	722	33.0
Apricots	320	33.9
Pears and Carrots	801	41.4
Beets	153	86.6

Table 2 illustrates the effect of various hydraulic rates and the importance of adding nutrients on BOD removals. At a high recycle to raw waste ratio (14:1) over 85 percent BOD removal can be obtained. As the ratio is decreased, the percent removal also decreases. The importance of nutrients, in this case diammonium phosphate, is illustrated by comparing the two columns on the right. The loadings were the same in each case but better removals were obtained when diammonium phosphate was added to the waste water. This was expected because the waste is low in nitrogen which is a requirement for good bacterial growth.

Table 2
Performance of Filter Unit based on
Removal of Biochemical Oxygen Demand (BOD)

Flow Rates (GPM)					
Raw Waste	1	3	5	7	7
Recycle Effluent	14	14	14	7	7
Total Flow	15	17	19	14	14*
Filter Performance (PPM BOD Removed)					
Influent	4033	3200	2700	3210	2750
Effluent	580	1395	1800	2040	1515
Reduction (%)	85.5	56.5	33.3	36.3	45.0

*Diammonium phosphate added

Figure 4 is a curve relating the effect of pH on the performance of the filter. It can be seen that the percent BOD reduction decreases with either a low pH or a high pH. The poor performance is a result of not

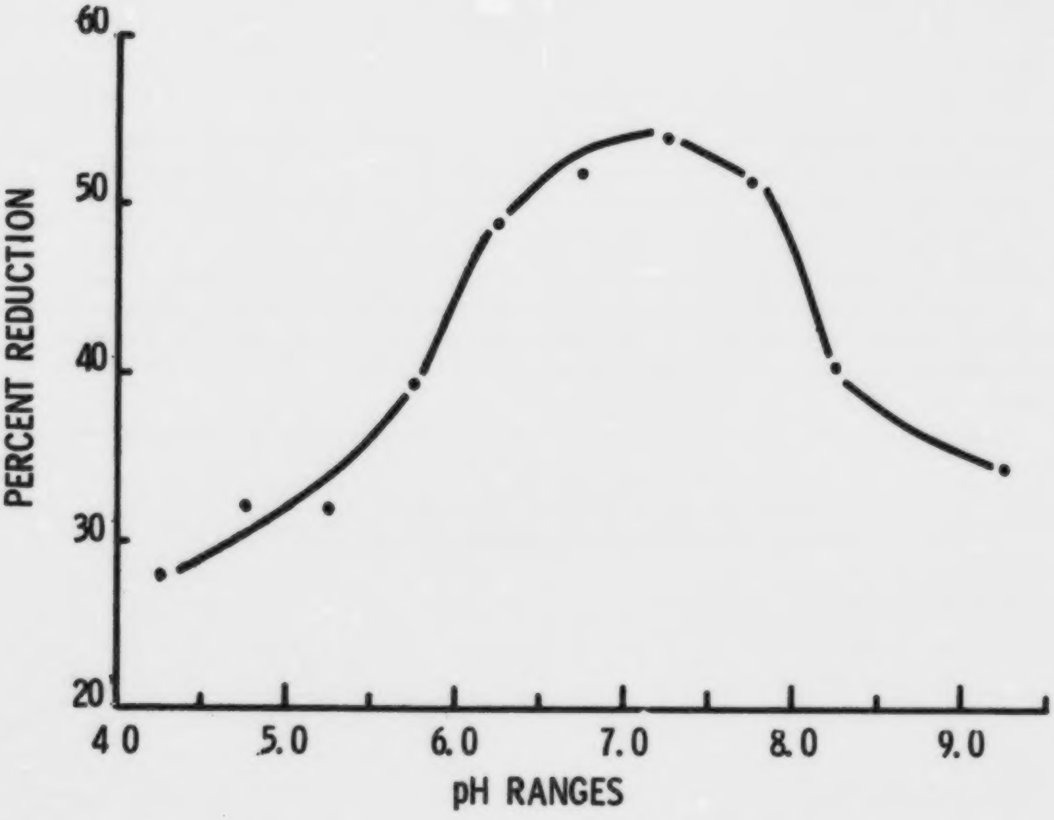

Figure 4. EFFECT OF pH ON BOD REMOVAL

providing optimum growth conditions for the microflora on the packing media. An acceptable pH range is between 6.5 and 8.0.

Figure 5 plots the effect of organic loading vs. percent reduction. As shown, the percent removal decreases as the applied load increases. Beyond a loading of 1500 lbs. BOD/day/1000 cu.ft. the removal drops off rapidly. At this and higher loadings, the filter has become saturated with organic matter and the microflora cannot remove additional quantities from the waste water.

Figure 6 is a schematic drawing of the second trickling filter system to be discussed. The screened waste passes through two 55 gallon drums then into one side of the wet well. A pump withdraws the waste from the sump and transports the liquid to the top of the filter. There, a motor driven-open trough distributor spreads the waste over the top surface of packing media. The waste flow, after passing down the filter, enters the other side of the wet well. A portion of the effluent overflows out of the sump and the remainder passes under the baffle to become recycled

This past season (1969) two intermediate sample points were added in addition to the normal influent - effluent sample points. The new sample points made it possible to obtain data on removals at different filter depths. The depths of the sample points are as follows:

A = 7.2 ft. from the top of the packing media
B = 14.4 ft. from the top
C = 21.5 ft. or effluent from the bottom of the filter

Figure 7 is a summary of the data collected last year and shows the percent removals at the various sample points. The first one third of the filter removed 28% of the total load removed by the filter. At 14.4 ft., 33 percent of the total load was removed and at 21.5 ft., 40 percent removed. Breaking down the removals by section we see that the top third of the filter removed 28 percent, the middle section removed an additional 5 percent and the bottom third removed the remaining 7 percent.

Figure 8 is another way of plotting the distribution of the pounds removed by each section of the filter. If we take the 40 percent that was removed by the total filter and determine on a percentage basis, the contribution of each section towards that removal, results are obtained as follows:

75 percent was taken out by the first 7.2 ft.
14 percent was taken out by the next 7.2 ft.
11 percent was taken out by the remaining 7.3 ft.

We believe there are at least two factors which contributed to the disproportionate removals at the different filter depths. First a

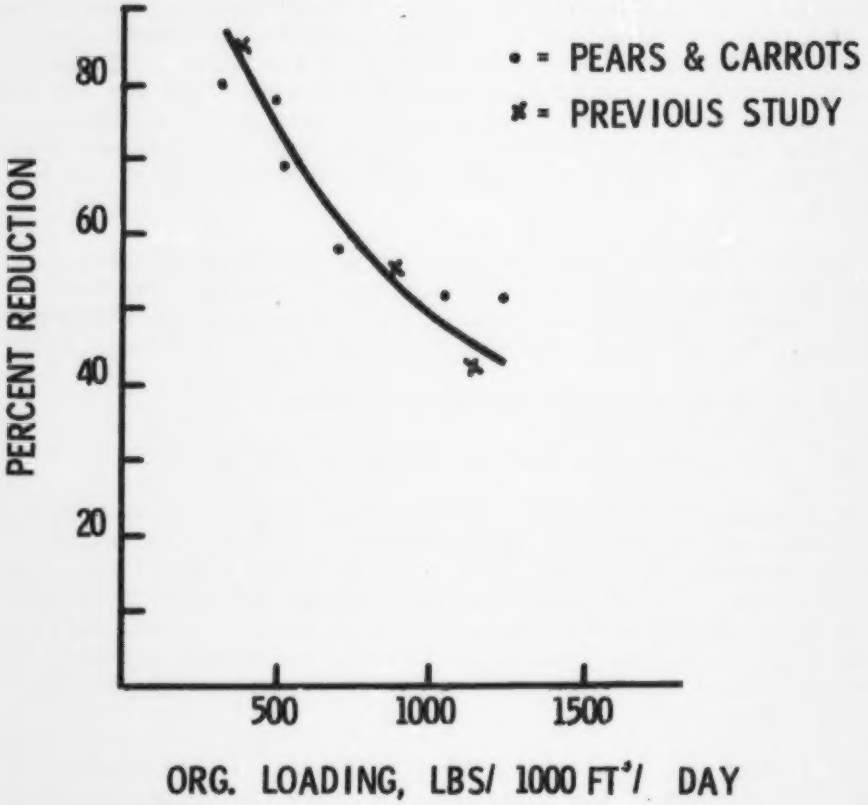

Figure 5. EFFECT OF ORGANIC LOADING ON BOD REMOVAL

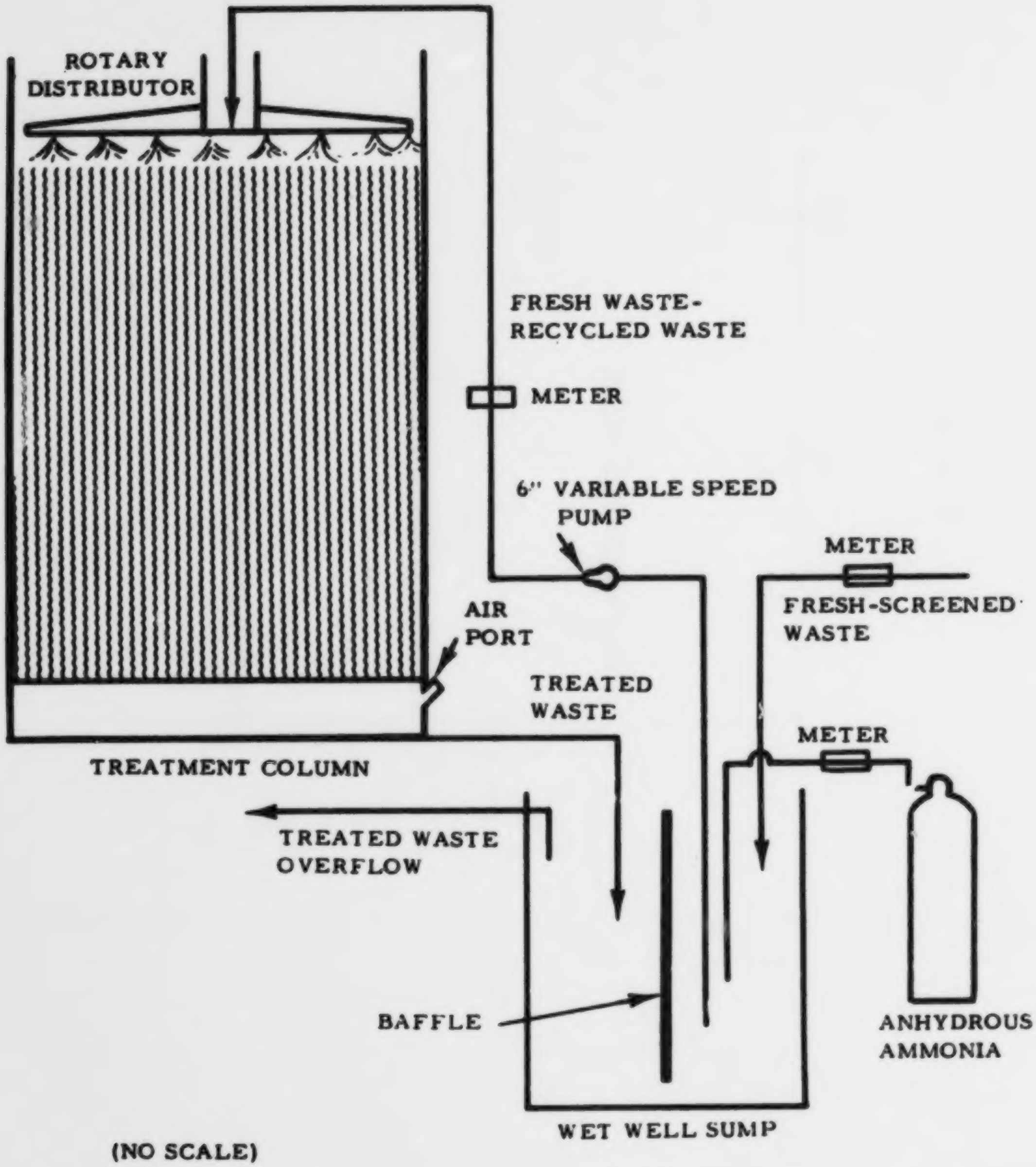
ROTARY DISTRIBUTOR
FRESH WASTE-RECYCLED WASTE
METER
6" VARIABLE SPEED PUMP
METER
FRESH-SCREENED WASTE
AIR PORT
TREATED WASTE
METER
TREATMENT COLUMN
TREATED WASTE OVERFLOW
BAFFLE
ANHYDROUS AMMONIA
WET WELL SUMP
(NO SCALE)

Figure 6. HIGH RATE TRICKLING FILTER SYSTEM

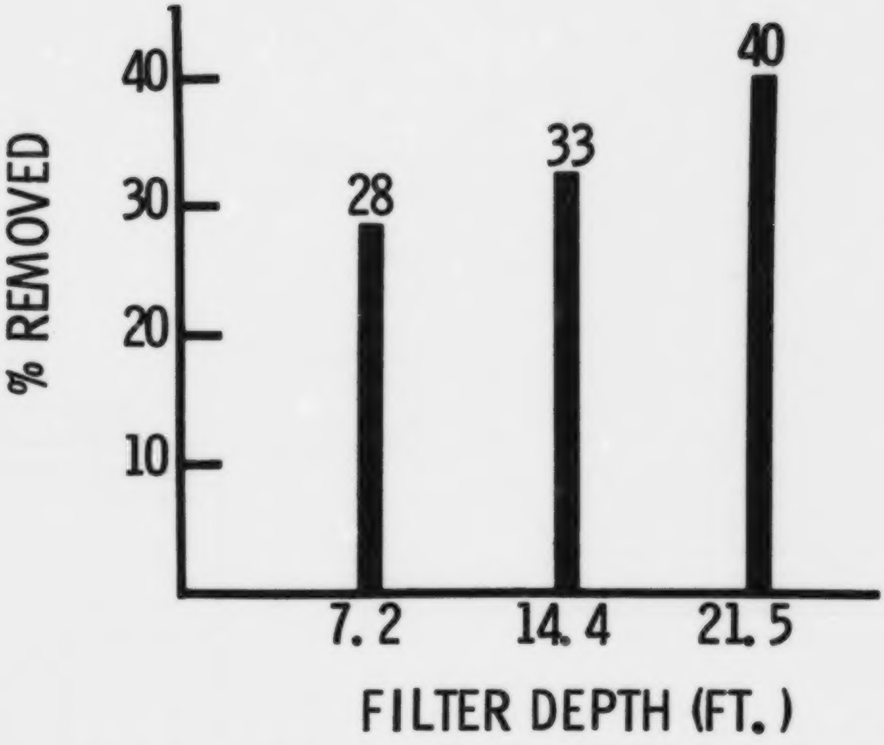

Figure 7. COD REMOVAL VS. FILTER DEPTH (NATURAL AERATION)

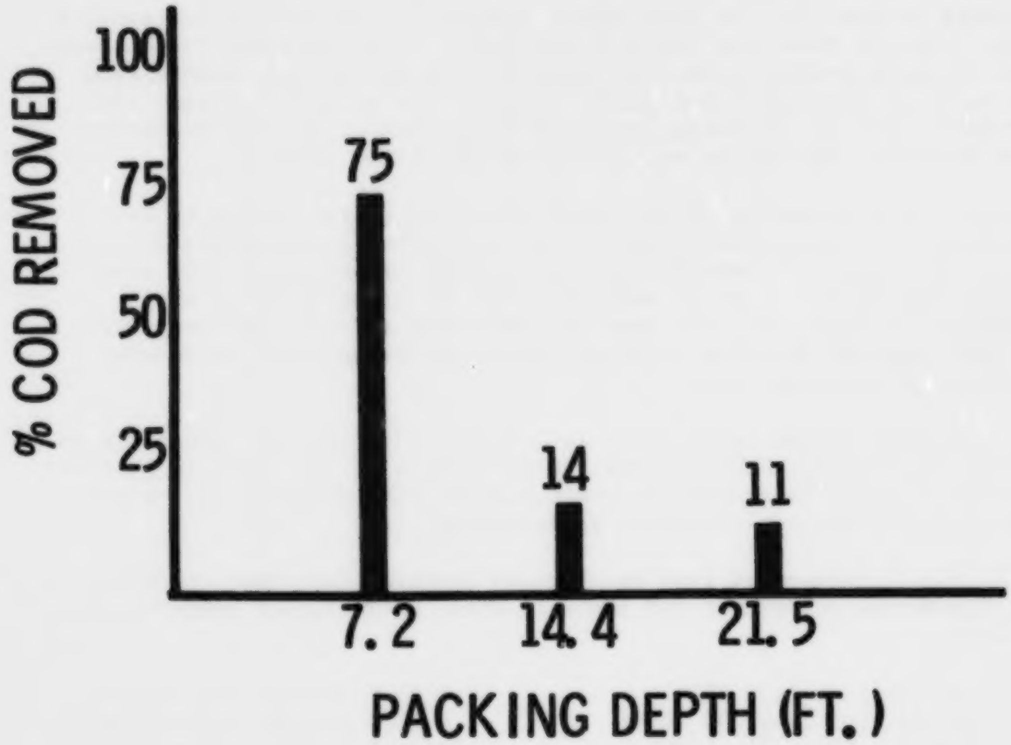

Figure 8. DISTRIBUTION OF TOTAL COD REMOVED

low hydraulic rate was applied to the filter. The raw and recycle rates were each 0.44 gpm/1 sq. ft. of cross sectional area. Second, fruit waste from peach and fruit cocktail processing was being fed to the filter. As indicated before, fruit waste is composed primarily of simple sugars and acids which are readily metabolized by bacteria. Therefore, a combination of low-flow and easily oxidizable compounds probably account for the high removals shown by the results for samples taken from the first one third filter depth. The remaining filter depth took out more complex compounds which are not as readily removed from the waste as the sugars and acids. Next season we will increase the hydraulic rate by increasing the flow of raw and/or recycle to determine if better use can be made of the total filter depth.

Figure 9 is a schematic of the third trickling filter system to be discussed. As indicated by the title, the unit has provisions for forced aeration and elevation of the influent temperature. The reservoir tank on the right is used to raise the temperature of the influent. A plate coil was used in 1968 which did not work very well. In 1969 this was replaced by direct steam injection which performed better than the plate coil.

The treatment column on the left is 3-3/4 ft. in diameter and contains 7.5 ft. of plastic packing media. Distribution of the waste is by fixed nozzles. Air is introduced at the bottom of the treatment column and measured by a manometer-orifice plate system.

Table 3 is a summary of 1969 results and compares the effect of three air flow rates on percent COD removals while operating at ambient temperature.

Low air flow (100 SCFM) = 15.9 percent COD removal
Medium air flow (200 SCFM) = 22.9 percent COD removal
High air flow (300 SCFM) = 28.8 percent COD removal

As indicated above, there was an improvement in removals as the air flow increased. Some dissolved oxygen determinations on the effluent indicated inadequate air flow at the lower flow rates. We did not have time to increase the air flow beyond 300 SCFM to determine if additional removals would be achieved. This will be considered in a test program for the 1970 season.

Some studies were made with this unit when operated in the thermophilic temperature range of 120°F. The results were not as good as expected but did indicate better removal rates than at ambient temperature. While evaluating this phase of the program, we did experience difficulties with the nutrient feed system and this may have contributed to the poor performance of the filter. The use of elevated temperature is another area that will be investigated in 1970 in an effort to optimize the operation of the high rate trickling filter system.

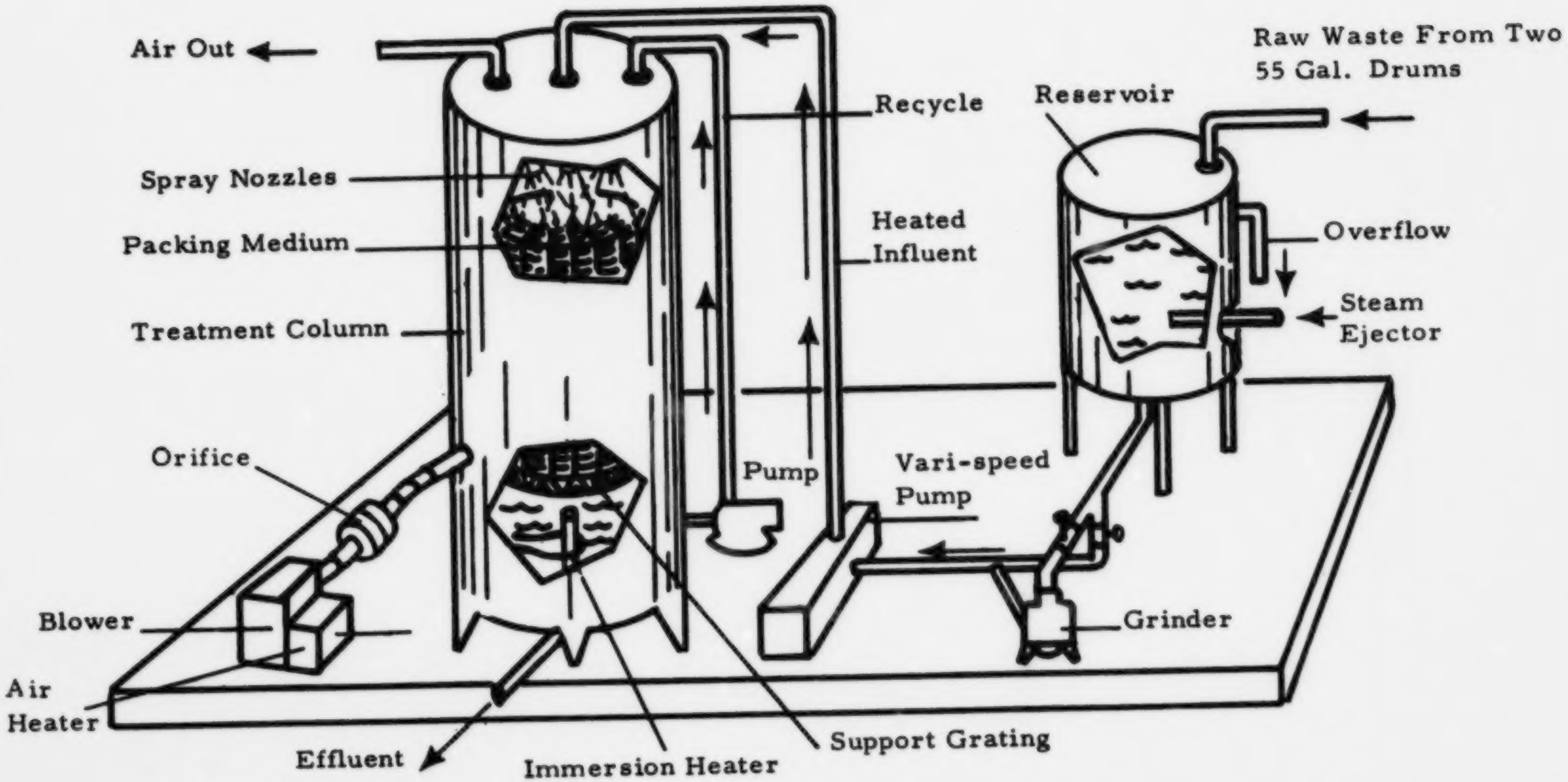
Air Out
Raw Waste From Two 55 Gal. Drums
Reservoir
Recycle
Spray Nozzles
Packing Medium
Heated Influent
Overflow
Steam Ejector
Treatment Column
Orifice
Pump
Vari-speed Pump
Blower
Grinder
Air Heater
Effluent
Immersion Heater
Support Grating

Figure 9. SCHEMATIC DRAWING OF FORCED AERATION, CONTROLLED TEMPERATURE TRICKLING FILTER. 1969

Table 3. Effect of Air Flow Rates on COD Removal at Ambient Temperature

Influent	Air Flow		
	Low	Medium	High
3580	3000 (15.9)*		
3400		2620 (22.9)*	
4180			2980 (28.8)*

*Percent COD removed

FOOD PROCESSING WASTE TREATMENT BY SURFACE FILTRATION

by

Louis C. Gilde*

A food processing plant can be in harmony with nature as witness the outstanding results of the Campbell Soup Company, Paris, Texas, plant whereby 3.6 mgd per day of wastewater are treated by a unique system accomplishing the equivalent of tertiary treatment. This is a new overland flow technique by which water sprayed on impervious or semi-pervious soils becomes purified by flowing through vegetative litter on the soil's surface and collects in terraces at the bottom of slopes. For over five years the system has averaged 99 percent BOD reduction with major reductions of nutrients. The before and after picture of Figure 1 shows how the badly eroded soil due to mismanagement of cotton farming was reconstructed and rehabilitated to uniform slopes and terraces for treatment purposes, thus becoming an outstanding example of soil conservation.

Detailed data were obtained on the system by conducting a one-year comprehensive survey to study the interacting relationship of climate, biological, and soil conditions. During this study, the Robert S. Kerr Water Research Center obtained data on the water balance and treatment efficiencies; Campbell Soup Company sponsored work by C. W. Thornthwaite Associates who investigated the microclimate and agricultural aspects, while North Texas State University evaluated the microbiological relationships. Campbell Soup Company also provided project coordination and on-site supervision of daily operations.

To accomplish this research, a pilot installation was set up where the conditions of waste treatment were carefully controlled. On approximately 15 acres of a functioning system consisting of 500 acres, detailed biological studies identified and enumerated the various species of microorganisms. Microclimatic data were recorded to provide insight into the microfauna flux as a function of temperature. Concurrently, the soil chemical changes within the pilot plant were related to microbiology and temperature. The effectiveness of this treatment was then evaluated according to the rate of application and the soil and temperature conditions. Evaluation of the agricultural economics of this disposal system was also included.

The spray irrigation disposal system of Campbell Soup Company in Paris, Texas, is one of four(1) overland flow systems in the country which have been installed on an area of impervious soil. Wastewater is applied

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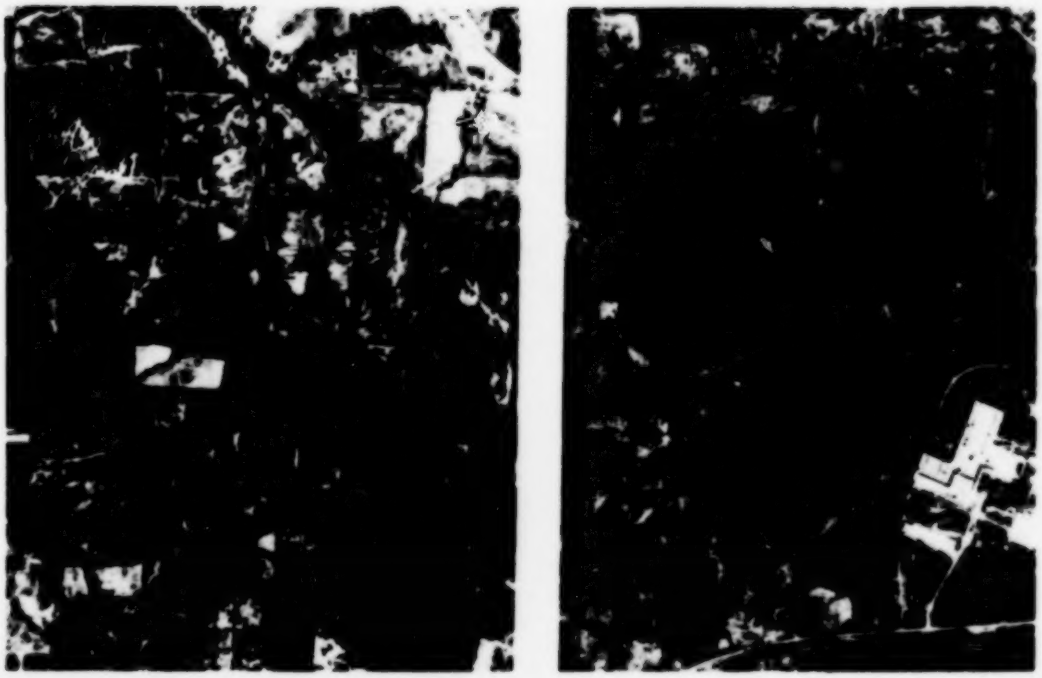


Figure 1. Before and after photographs represent an excellent example of soil conservation practice by adapting badly eroded non-usable farmland to carefully rehabilitated uniform slopes and terraces for treatment. The erosion gullies in some places were deep enough and wide enough to hide completely a D-7 Bulldozer.

along the top of a carefully prepared slope and becomes purified by flowing through the vegetative litter on the soil surface and is collected in a collection terrace at the bottom of the slope. Since the only significant water loss is through evapotranspiration, it follows that this technique is exceptionally well adapted for the collection and reuse of treated water. It is also evident that the overland flow method of treatment can be used in areas where an impervious soil or a high water table would have ruled out the possibility of conventional spray irrigation that normally relies upon infiltration.

The phases of the investigation included: (1) climatology, (2) biology, (3) chemistry, and (4) agriculture. The climatological investigations included an official weather station which was established to record rainfall, maximum and minimum temperatures, and provide a continuous record of relative humidity. The record was made of the soil heat flux at selected levels below the surface. Net radiometers were used to record the difference in energy balance between sprayed and unsprayed areas.

The biological program involved identification and enumeration of microorganisms (bacteria, fungi, algae, protozoa, etc.) which exist in the spray fields and compared these populations with those in control fields. Physiological activities of certain selected microorganisms were studied to isolate and identify specific segments of the microbial population that were responsible for the degradation of the organic substances in the wastewater. Evaluations were also made of the effect upon the microbial population produced by the use of certain insecticides.

Chemical analyses as conducted by the Robert S. Kerr mobile laboratory facilities followed classical analytical tests normally associated with pollution control programs.

Finally, the agricultural evaluation took into consideration the growth index and hay quality along with the harvest rate for various disposal potentials. This study involved the logistic problems of large-scale harvest while continuing to operate the system for treatment purposes.

In order to evaluate the agricultural economics of the disposal system, samples of fodder were collected during the growing season and analyzed for animal nutrient value and palatability. Growth indices and evapotranspiration loss were evaluated according to microclimatic data. Evaluations were made of the rate of harvest related to the gain or loss in disposal potential.

DESCRIPTION OF PARIS SYSTEM(2)

The effluent arrives at the waste treatment building from two sources within the factory. The first, containing grease from the cooking area, passes through a gravity grease separator. It then joins the stream from the vegetable washing area and the combined flow passes through 10-mesh screens to remove large pieces of solids. From here the water is pumped to the disposal field at high pressure.

The treatment system consists of some 30,000 feet of underground force main, 50,000 feet of portable aluminum irrigation pipe above ground, and 180,000 feet of control tubing in the ground operating 77 pneumatically controlled valves. There are over 700 sprinklers in the system varying in size from 14 gpm to 30 gpm, depending upon the particular treatment capabilities of the individual slopes on which they are located.

The entire system is controlled automatically. Three clock timers similar to golf course watering systems are connected electrically to each of the five high pressure pumps. As the water level in the surge tank rises, each pump is started in turn and energizes its own clock timer, which automatically opens the valves in the field that are programmed to that pump. When a sprinkling cycle for one group of lines has been completed, the timer automatically advances to the next group and so on until all sprinkler lines have received their predetermined allotment of water. A plug board provides for convenient regrouping of lines as field conditions or harvesting schedule requires.

Prior to initial operation, the heavy clay soil on the 500-acre tract was remolded to form watersheds of two to ten acres each, depending upon the lay of the land and the natural watercourses. Each watershed is from 200 to 300 feet wide and pitched toward a collecting terrace at the foot of each slope. The land was then land-planed to smoothness and planted to water-tolerant grasses. Near the top of the slope, irrigation sprinkler lines run parallel to the collection terrace at the bottom. Wastewater from the factory is discharged from the sprinklers and flows slowly downhill in a thin sheet, becoming purified enroute through microbiological activity. The purified water is then collected at the terrace and flows to the receiving stream via a prepared waterway. The basic concept of the system is diagrammed in Figure 2.

The grass which has been planted upon the slopes serves a multi-purpose function. First, it protects the soil surface from erosion and retards the flow of water across the slope. Next, it provides a protected habitat for microorganisms and a vast surface area for the adsorption of impurities contained in the water. Finally, when cut for hay it is a valuable cash crop and provides an effective means for reclaiming plant nutrients which are released in soluble form when the organic waste material decomposes.

DISCUSSION OF RESULTS OF ONE-YEAR RESEARCH PROGRAM(3)

The work in climatology centered around the establishment of a temperature-moisture base which could be related to weather bureau records throughout the world. To accomplish this, temperature, rainfall, and relative humidity data were tabulated for several locations within and without the disposal tract and at several levels above the ground. In addition, the net radiation and soil heat flow were also recorded. The data showed a remarkable similarity in all locations with the mean temperatures, differing only a degree or two. Furthermore, there was no consistent pattern to indicate that one observation site was usually higher or lower than any of the others, except that the U. S. Weather Bureau Station in the City of Paris usually recorded higher temperatures than the duplicate

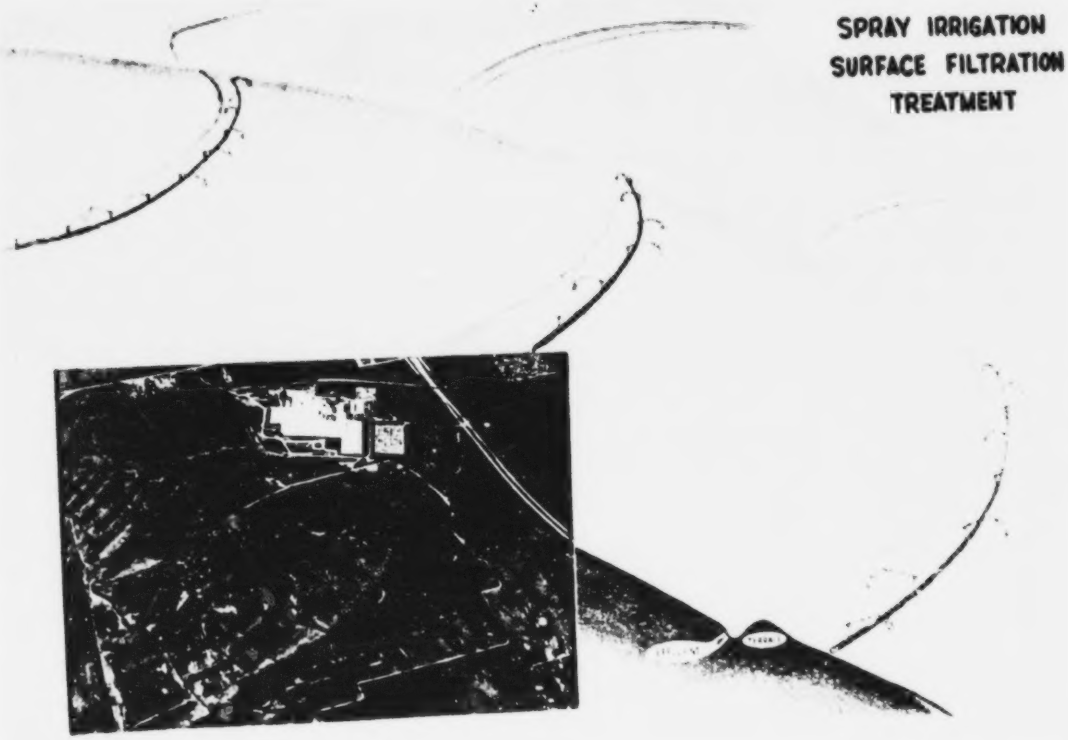

SPRAY IRRIGATION
SURFACE FILTRATION
TREATMENT

Figure II

equipment located in the disposal area. Unquestionably, this was due to buildings near the city observation site. The same lack of pattern was noted in the observations of relative humidity. Soil heat flux and net radiation did show differences between wet and dry areas, but no more so than would be expected. Thus, it can be said that the growth of grass upon the disposal field responds to temperature and moisture in the same manner as any hay field in the humid east and that any U. S. Weather Bureau records can be used to predict growth rates anywhere in the east.

From the temperature and rainfall data, potential evapotranspiration was calculated by means of the Thornthwaite formula. This, in turn, was used in the hydrology studies. It was also used to plot growth rate curves, predict hay harvest dates, and relate hay quality to growth rates.

During the season three cuttings of hay were made and reserved for later palatability tests. In addition, weekly samples were collected for nutritional and chemical analysis. The analysis results showed the Reed Canary grass which had been grown on the disposal tract was of exceptionally high nutritional value ranging up to 23 percent crude protein. The mineral content was also high, nearly double the quantity found in other good quality hay. Thus, harvest of hay provides an efficient method of reclaiming part of the plant nutrients which are released when the vegetable matter contained in the effluent decomposes. When the feeding tests were conducted, cattle exhibited a definite preference for hay grown on the disposal sites.

An attempt to relate potential evapotranspiration to soil tractionability(4) was disappointing because of the exceptionally high rainfall during 1968. The rainfall also delayed the general harvest of the entire tract, resulting in a loss of quality.

The chemical investigation was primarily directed toward determining the fate of phosphorus and nitrogen, but included much other work as well, including BOD evaluation, a record of dissolved oxygen, pH and conductivity and an analysis of mineral salts contained in the soil. To accomplish this, four watersheds were selected and isolated so that only wastewater and rainwater would flow across the area. Several sampling stations were located within the sprinkler pattern to collect raw waste and proportional samplers were located at the outfall of the watersheds. The four watersheds represented two soil types, one each in areas which had operated four years and one each in areas operated for two years. These areas received similar quantities of water as all other watersheds in the disposal system.

Early observations revealed that while BOD and nitrogen removal were high--99 and 90 percent respectively--the removal of phosphorus was disappointingly low, about 45 percent. A later change in the operating procedure to provide a longer rest period between applications, with no change in the total volume increased the phosphorus removal to nearly 90 percent without affecting the BOD or nitrogen removal.

Table 1. Treatment Efficiency of the Overland Flow System

Parameter	Mean Concentration, mg/l		Percent Removal	
	Wastewater	Section Effluent	Concentration Basis	Mass Basis
Total suspended solids	263	16	93.5	98.2
Total organic carbon	264	23	90.8	-
Biochemical oxygen demand	616	9	98.5	99.1
Total phosphorus	7.6	4.3	42.5	61.5
Total nitrogen	17.4	2.8	83.9	91.5

It is interesting to note that the disposal field acts as a buffering agent and maintains the field effluent close to neutrality while the factory effluent ranges widely over the pH scale. This is clearly shown in Figure 3, which follows, showing the diurnal variation of pH for the wastewater applied to the slopes and the field effluent.

The same condition is obtained for the diurnal variation of electrical conductivity shown in Figure 4.

Analysis of groundwater samples showed that while mineral salts had increased markedly in the old area, the total accumulation was not critical and there was some indication that the rate of increase might be lessening.

H-type flumes were installed at the outfall of each watershed and equipped with instruments to record the water depth. A complete water balance was obtained from a known quantity of water being applied and measurement of runoff, spray evaporation, evapotranspiration, and deep soil percolation. The water data is believed accurate to plus or minus ten percent. Water balance measurements accounted for 93 percent of the total liquid applied, runoff measurements accounted for about 61 percent, and the remaining 21 percent percolated through the soil. Table 2 summarizes the hydrological data for the area studied.

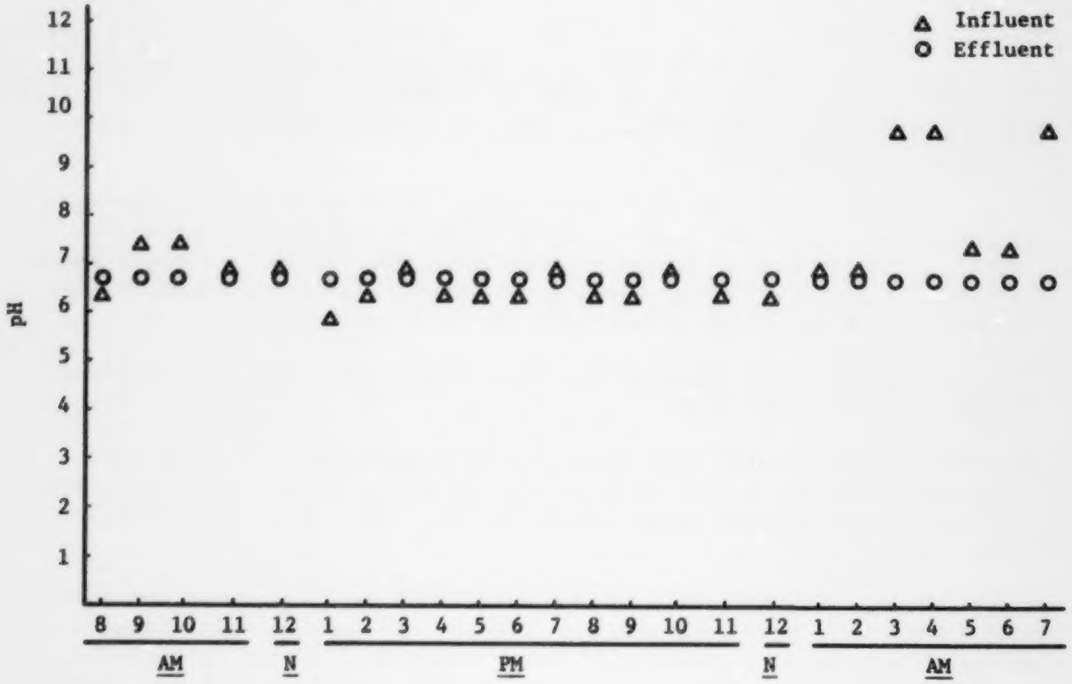


Figure 3. DIURNAL PH VARIATION

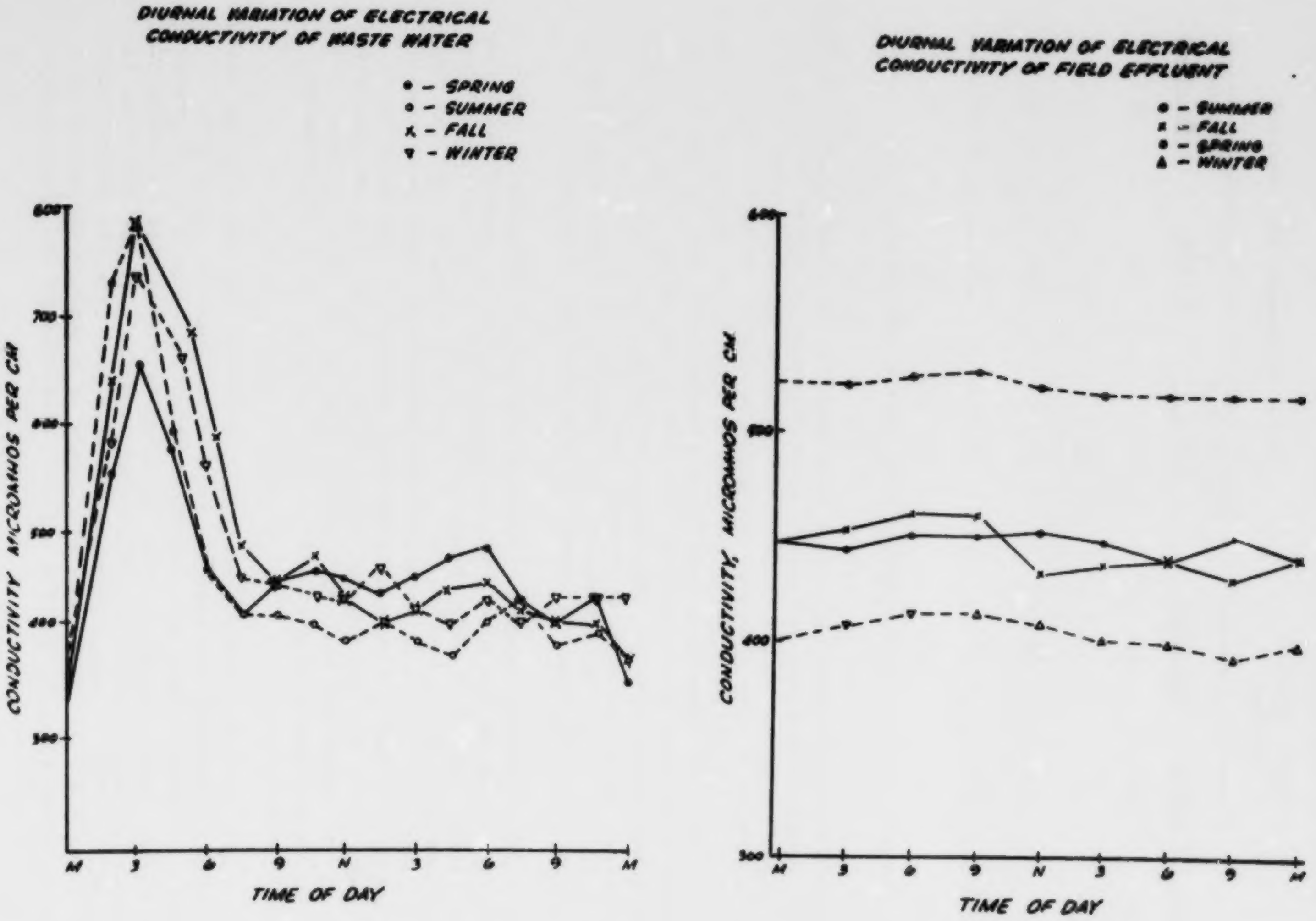

DIURNAL VARIATION OF ELECTRICAL CONDUCTIVITY OF WASTE WATER
● – SPRING
○ – SUMMER
X – FALL
▽ – WINTER
CONDUCTIVITY MICROMHOS PER CM
800
700
600
500
400
300
M
3
6
9
N
3
6
9
M
TIME OF DAY
DIURNAL VARIATION OF ELECTRICAL CONDUCTIVITY OF FIELD EFFLUENT
● – SUMMER
x – FALL
● – SPRING
▲ – WINTER
CONDUCTIVITY, MICROMHOS PER CM.
600
500
400
300
M
3
6
9
N
3
6
9
M
TIME OF DAY

FIGURE IV

Table 2. Hydrology of the Overland Flow Treatment System

	Water Applied Percent		Water Accounted for, Percent		
Season	Spray	Rainfall	Evaporative losses	Runoff	Deep-soil percolation
Spring	76	24	23	56	21
Summer	86	14	28	55	17
Fall	73	27	13	64	23
Winter	63	37	10	68	22
Annual	74	26	18	61	21

Perhaps the most interesting single fact emerging from the study in biology is the reason behind the continued high efficiency in winter(5). It has long been recognized that a system would continue to purify water when temperatures were near freezing, but since it is also known that the respiration of microorganisms slows down as temperature decreases, it was believed that the impurities were being adsorbed upon the surface of the vegetation and held there until the weather warmed again. Biological studies have shown that as temperature decreases the number of organisms increases, thus maintaining a constant level of mass activity. This fact places the importance of adsorption in a position of lesser significance. The increase in organisms in winter is clearly shown in Figure 5.

Other work in biology sought to identify the groups of organisms which were actually doing the work and revealed an extremely complex and changing ecology. Composite samples were taken at the top and bottom of two watersheds and also on the control lot. The data revealed that the sum of the three most populous organisms represented less than 50 percent of the total, indicating a very heterogeneous population. As might be expected, the population density was greater at the top of the watershed than at the bottom and both were greater than on the control, thus reflecting the effect of a diminished food supply. This condition is shown in Figure 6.

Since the type of organisms present in the control and those in the test plot were essentially the same, it is inferred that the microflora naturally present in the soil are those responsible for the biodegradation of the waste. However, other experiments showed that the oxidative activity of samples inoculated with soil from the disposal field was far greater than that of samples inoculated with soil from the control plot. This would indicate either an evolutionary or a seeding process whereby microorganisms specific for the effluent developed on the disposal site.

FIGURE V

TOTAL MICROBIAL POPULATION
ON CONTROL AND TEST LOTS

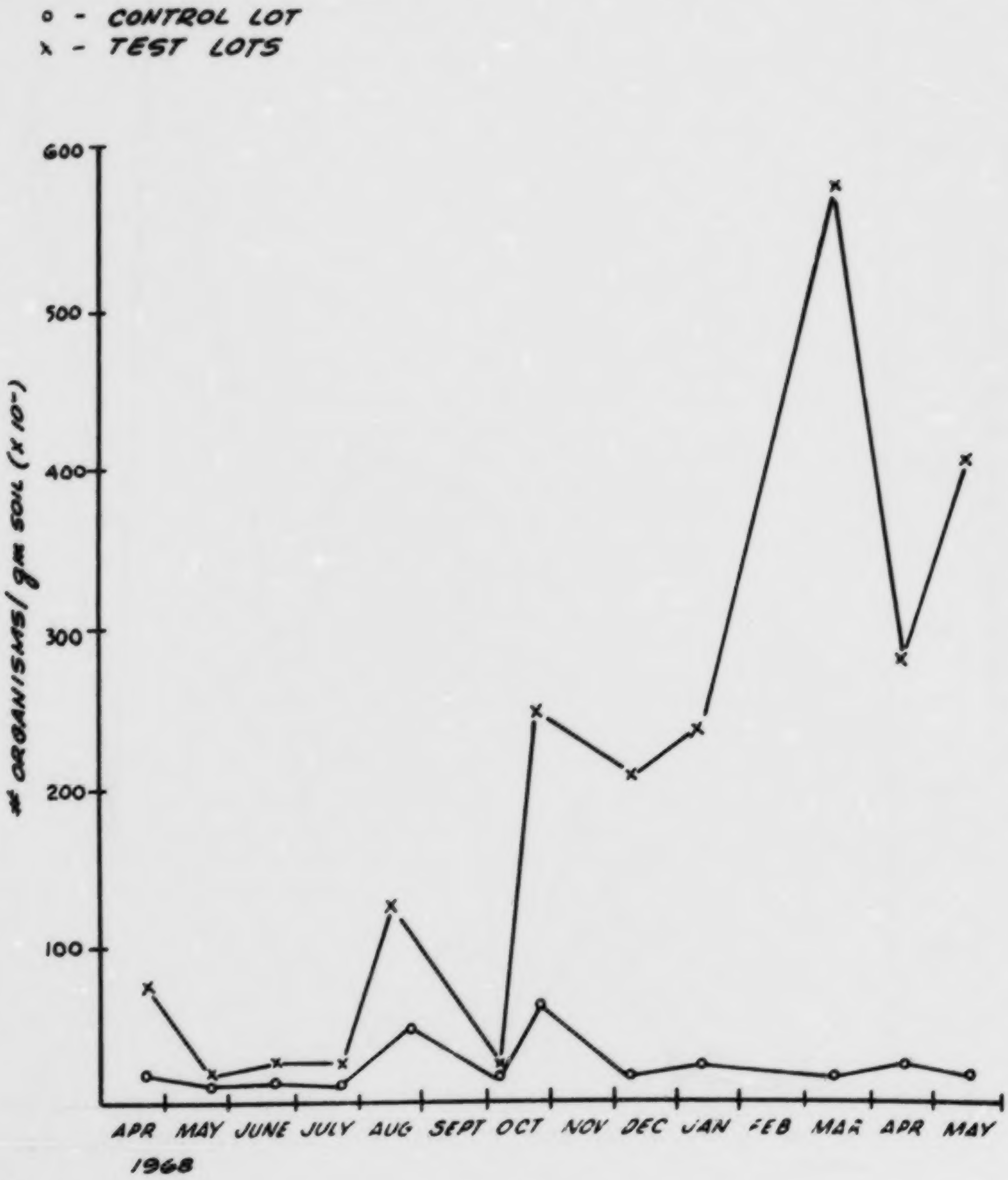
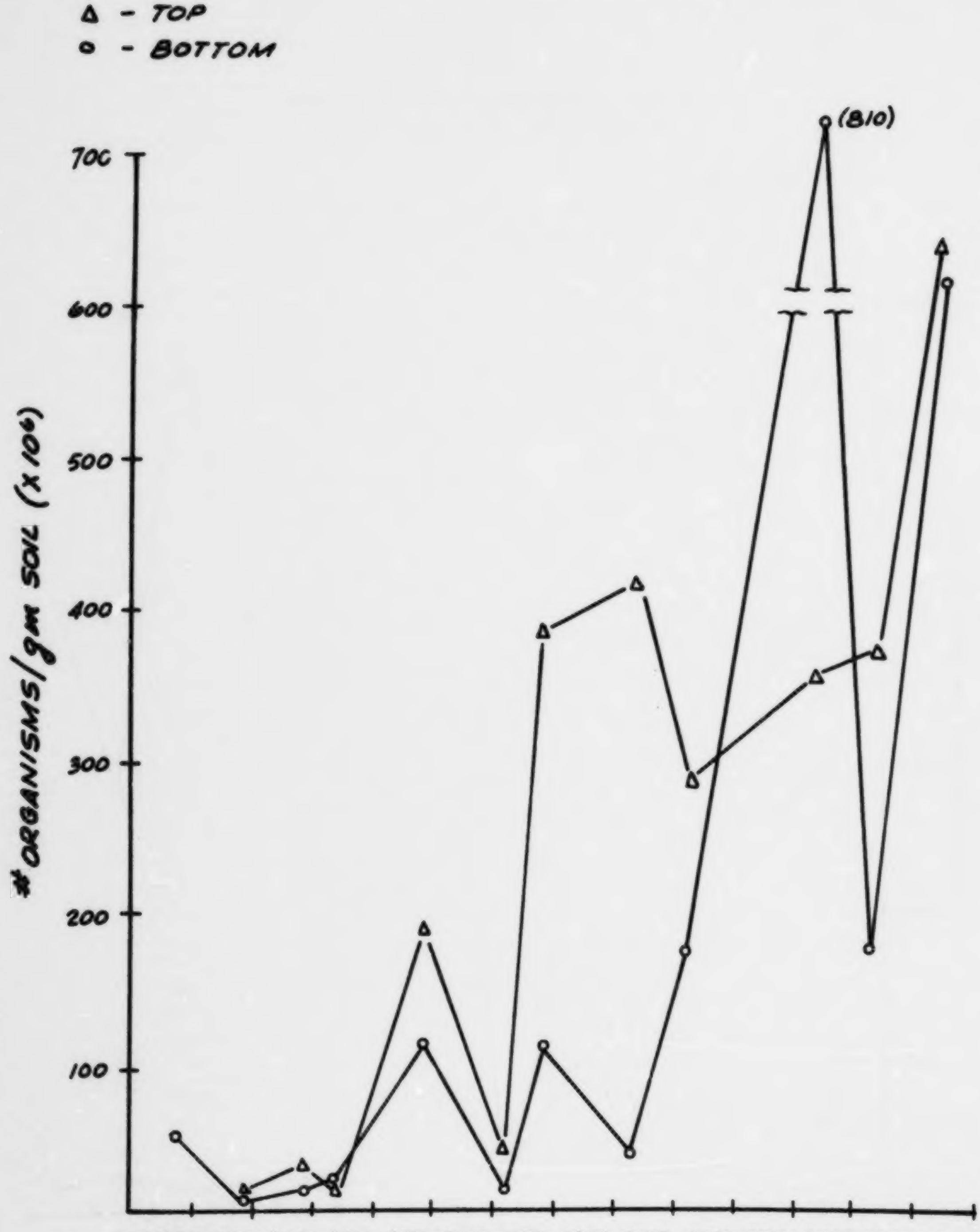


FIGURE VI

TOTAL MICROBIAL POPULATION ON TOP AND BOTTOM OF SLOPE ON TEST LOTS



One might speculate that the time required for the evolutionary process is one reason for the apparent greater capacity of an older disposal system. A similar speculation suggests that the maturing of the system might be hastened by seeding it with specific organisms.

It was also shown that some soils will support microorganisms much better than others in the laboratory. The significance of this on a complete field system is not known since no individual area or slope could be identified as being less efficient due to soil character or structure.

The overland flow system has the outstanding capability of handling shock loads on the one hand and periods of long shutdown and immediate start-up on the other, producing excellent results in either case. In addition, wide variations in effluent character, such as occur during night cleanup, produce no adverse effects. Also, if a single terraced slope is accidentally overloaded or suffers a mechanical failure, the effluent treatment continues in the long terraces and waterways before the effluent reaches the receiving stream. In other words, a great deal of "fail-safe" capacity is naturally built into the system.

CONCLUSIONS RELATED TO DESIGN PARAMETERS

The Paris system was designed with the length of downhill slope from 200 feet to 300 feet. Studies in 1968 showed that 175 feet would give effective purification,and there is strong suspicion that 150 feet is sufficient at this site, provided the slope is not too great. Basically, the downslope area requirement is 50 feet beyond the perimeter of the sprinklers.

The pitch of slopes in Paris ranges from less than one percent to more than twelve percent. The investigation led to the conclusion that a flat slope encouraged puddling and subsequently anaerobic conditions, while the retention time on a steep slope was insufficient for complete degradation at normal application rates. This established a design criterion of no more than six percent, but not less than two percent for any slope.

In Paris the design was based upon an application rate of 0.25 inch per day in winter and 0.50 inch per day in summer based upon an estimated wetted area coverage of approximately 75 percent. As it turned out, the actual wetted area was considerably less than the estimate, but the disposal capacity per wetted acre was much greater. The greater hydraulic load capacity combined with more efficient land utilization results in a more compact system requiring less acreage. The application to wetted watershed in the test areas was normally 0.6 inch per day or 3.0 inches for a five-day week. During the summer of 1968, the duration of the sprinkling cycle was increased from 6 to 8 hours per day, while hay harvest was in progress.

Reed Canary grass will yield a large quantity of exceptionally high quality hay which, according to nutritional analysis, approximates the value of first quality alfalfa. The number of harvests which may be undertaken during the growing season has not been completely established but certainly one and probably two harvests are feasible. The study further established that late harvest of a third crop resulted in a poor quality crop because of over-maturity. The value of the hay, however, was about 8 percent of the operating cost of the system.

The spray irrigation technique of wastewater disposal is now being used widely throughout the food and wood products industry. Most of these installations achieve a high degree of water purification, but the use of this technique is usually limited to soil areas with high infiltration capacity, and thus the purified water is usually lost to the original user. The system at Paris, Texas, is a notable departure from the usual spray irrigation concept, since it employs the overland flow technique whereby water is applied to impervious soil and the purified effluent is collected at the foot of a vegetative slope. Thus, consideration can be given to the collection and reuse of water from such a system.

This technique has been developed to the point that an exceptionally high degree of waste purification has been demonstrated. The system at Paris, Texas, has averaged in excess of 99 percent reduction in BOD for over five years. This technique now extends the highly efficient performance to areas of impermeable soils where its use was formerly considered impossible.

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BIOLOGICAL TREATMENT OF FOOD PROCESSING WASTES

by

Perry L. McCarty*

The principles of biological waste treatment have been developed to a high level of understanding over the past twenty years. The papers presented during the first two days of the National Symposium on Food Processing Wastes have shown that these principles now are being used successfully for the solution of practical waste treatment problems. The success which is being achieved clearly demonstrates that the relatively few years and few dollars spent by the Federal government for basic research on biological processes had paid-off decidedly.

No longer is it necessary to consider each different waste as being highly unique and requiring years of empirical trial and error research to reach a practical solution to a waste treatment problem. No longer is it necessary to continue polluting streams with organic waste because of the absence of suitable methods for removing organic materials from waste effluents. Full scale treatment systems can be designed, can be built, can be operated, and can be depended upon to achieve a high efficiency of treatment. This can usually be done now with a relatively straight-forward waste characterization and with only limited laboratory studies.

This paper is a summary of the basic principles which have been applied and discussed during the first two days of this Symposium. During this time, twelve papers primarily concerned with the use of biological processes for treatment of food processing wastes were presented. Eleven of the papers dealt primarily with the use of aerobic systems, with major emphasis on the activated sludge process. The anaerobic treatment process, however, was discussed in only three of the papers. The later process has some important advantages for treatment of food processing wastes, but has not been widely used to date. This is partly due to a former lack of understanding of the process, but this deficiency has largely been erased during the past decade. Additional emphasis on the anaerobic process will be given in this paper.

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PRINCIPLES OF BIOLOGICAL TREATMENT

The engineer can consider the design of a waste treatment system similar to the way in which he considers the design of a structure. He determines first the stresses which can be placed upon his materials before failure is reached. He does not design for this failure point, but applies a safety factor. The magnitude of the safety factor is based upon judgements which consider possible overloads on the system, sudden and localized stresses, temperature effects, permissible strains on the system, and allowance for unknown or non-calculable risks.

The ultimate stress which can be placed upon a biological treatment system before failure is related to the maximum reproduction rate of the microorganisms involved. If the system is stressed to the point at which the microorganisms are being removed from the system faster than they can reproduce themselves, then failure will result. This is closely related to another phenomena, the maximum rate at which microorganisms can consume food. If efforts are made to force them to consume more food than their physiological ability allows, then the process will fail. The failure point for biological systems can be evaluated from a consideration of the kinetics of bacterial growth and waste utilization.

Process Kinetics

The growth of microorganisms as a function of time after they are mixed with organic wastes is generally (2) estimated from the following equation:

$$dX/dt = Y(dF/dt) - bX \qquad (1)$$

where:

dX/dt = Net growth rate of microorganisms in mass per unit time,
dF/dt = Rate of waste utilization in mass per unit time,
X = Mass of microorganisms present,
Y = Growth yield coefficient in mass or organisms produced per unit mass of waste consumed,
b = Organism decay coefficient, time^{-1}.

Equation 1 states that the rate of growth of microorganisms is proportional to the rate of waste utilization (dF/dt), minus the loss in microbial mass due to decay (bX). In biological processes the mass of active microorganisms is frequently assumed to be equal to the volatile suspended solids in the system. However, the actual mass of active organisms may represent only a small fraction of this, the exact proportion depending upon the quantity of other organic suspended solids present.

The rate at which organic matter is utilized by microorganisms is a function of the concentration of a limiting nutrient as illustrated in Figure 1. In waste treatment, the organic waste itself is generally the limiting nutrient. However, with food processing wastes required inorganic nutrients such as nitrogen and phosphorus are often limiting and should be added for optimum rates of treatment and for good removal efficiency.

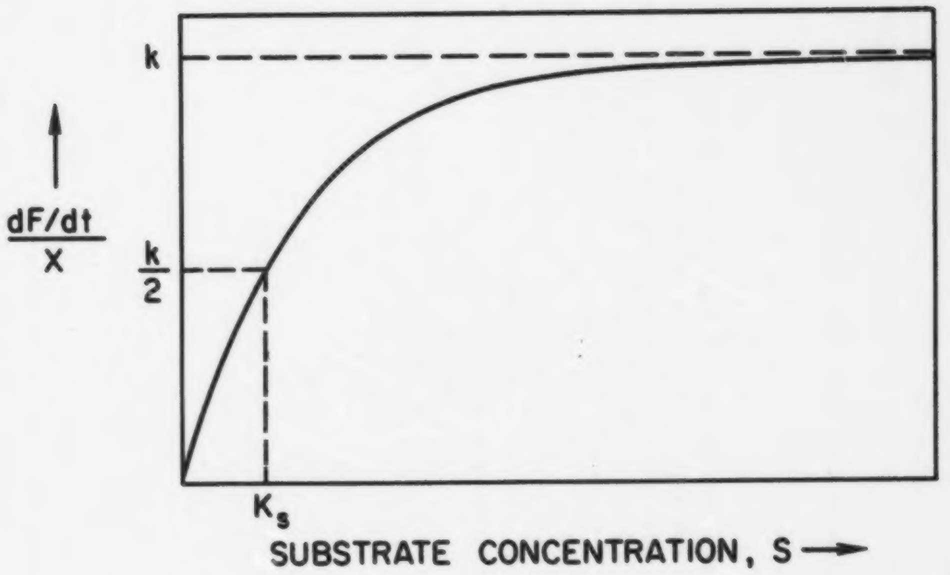


Figure 1. EFFECT OF WASTE CONCENTRATION, S, ON SUBSTRATE REMOVAL VELOCITY (dF/dt/X)

Monod (1) presented a relationship similar to the following to describe the effect of waste concentration on rate of waste utilization as illustrated in Figure 1:

$$\frac{dF}{dt} = \frac{kSX}{K_s + S} \tag{2}$$

where:

k = Maximum rate of waste utilization with high waste concentration,
K_s = Waste concentration at which the rate of waste utilization is 1/2 the maximum rate,
S = Concentration of waste surrounding the microorganisms.

Equation 2 can be rearranged to give the following:

$$\frac{dF/dt}{X} = \frac{kS}{K_s + S} \tag{3}$$

The ratio $(dF/dt)/X$ is commonly called the substrate removal velocity or the food to microorganism ratio. It represents the rate of waste utilization by a unit mass of microorganisms. The maximum removal velocity as illustrated in Figure 1 is equal to k and is achieved at high waste concentrations. This represents the upper limit for any biological process above which failure results. Much lower removal velocities than this maximum must be maintained for dependability and efficiency. A low removal velocity is obtained by adding a small amount of waste to a large reactor containing a high concentration of microorganisms.

If Equations 1 and 2 are combined, the rate of growth of microorganisms as a function of waste concentration can be obtained:

$$\frac{dX/dt}{X} = \frac{YkS}{K_s + S} - b \tag{4}$$

where $(dX/dt)/X$ is the net specific growth rate of the microorganisms in units of time^{-1}. The maximum growth rate is obtained at high waste concentration and equals $(Yk - b)$.

A schematic diagram for a typical biological process is illustrated in Figure 2. A waste with flow rate Q and waste concentration S_o is treated in a biological reactor with volume V. In the reactor, a mass of microorganisms, X, metabolize the waste and reduce its concentration to S, after which the microorganisms and remaining waste pass to a settling chamber where the microorganisms are removed from the waste stream. Considering that the settling tank is small in volume compared to the biological reactor and that no biological action takes place there, the concentration of waste in the treated effluent, S would be the same as in the reactor. The settled microorganisms are recycled and mixed with new incoming waste for treatment. If waste were continuously added to this system, the microorganisms would grow in mass until the system could

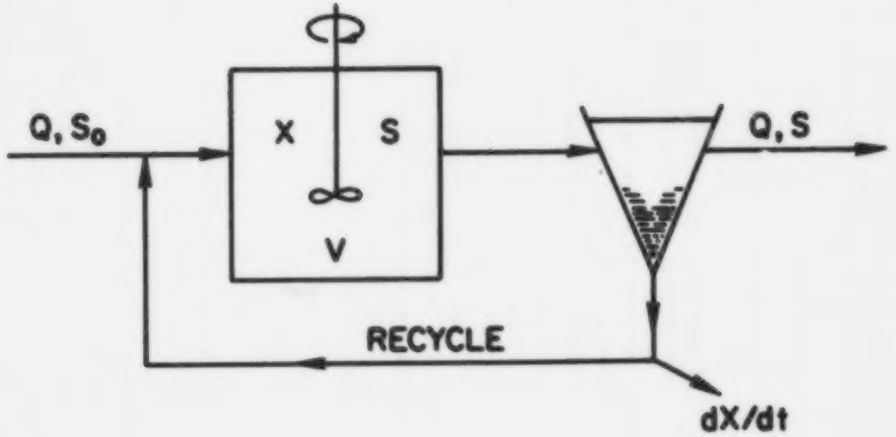

Q, S₀
X
S
V
Q, S
RECYCLE
dX/dt

Figure 2. SCHEMATIC DIAGRAM OF A TYPICAL COMPLETELY-MIXED BIOLOGICAL PROCESS WITH RECYCLE

no longer hold them. At this point, the excess microorganisms produced each day (dX/dt) would have to be removed from the system or else they would fill the settling tank and would pass out with the treated effluent, deteriorating its quality.

Continuous operation with deliberate wasting of a fixed quantity of microorganisms would soon lead to steady-state conditions of waste stabilization and microorganism growth. The rate of waste treatment, dF/dt, is equal to $(S_o-S)Q$, and the percent efficiency of waste treatment is $100(S_o-S)/S_o$. For high efficiencies of treatment, the concentration of waste in the effluent, S, must be small. This concentration based on Equation 3 is a function of the substrate removal velocity, or based on Equation 4 is a function of net specific growth rate. The reciprocal of growth rate is more convenient for use and gives the solids retention time (θ_c), or sludge age, which represents the average retention time of microorganisms in the system:

$$\theta_c = X/(dX/dt) \qquad (5)$$

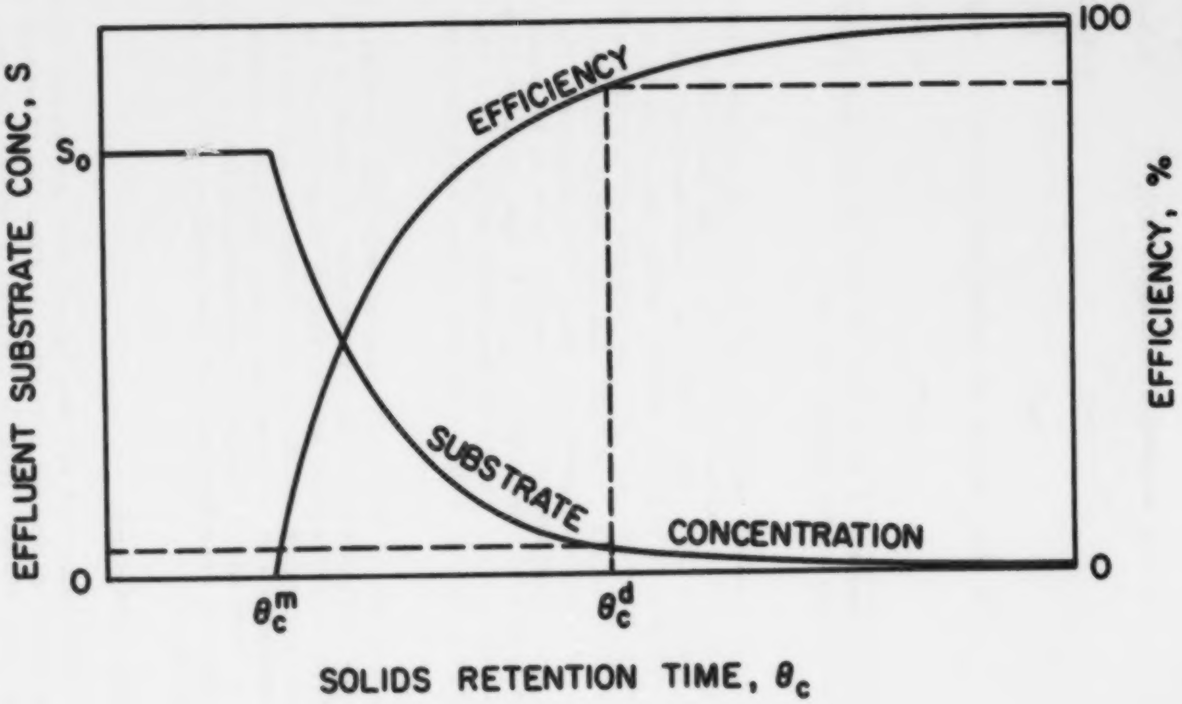
The value for θ_c is obtained by a suspended solids balance on the overall treatment system:

$$\theta_c = \frac{\text{suspended solids in system}}{\text{suspended solids removed from system per day}} \qquad (6)$$

The suspended solids removed per day include both the solids taken from the system deliberately as well as those which pass out unintentionally with the effluent. Figure 3 illustrates the relationship between effluent waste concentration and θ_c. As θ_c is decreased, the concentration of waste in the effluent increases. There is a minimum θ_c below which the treatment process will fail and is reached when the organisms are removed from the system faster than they can reproduce themselves and "wash-out" or loss of microorganisms responsible for treatment results. This minimum solids retention time, θ_c^m, can be approximated by the following formula, derived from Equations 4 and 5, by considering b to be negligible and S to be much larger than K_s:

$$\theta_c^m = \frac{1}{Yk} \qquad (7)$$

Table 1 summarizes the usual ranges of the kinetic coefficients for both aerobic and anaerobic processes (2) (3). The maximum rate of waste utilization, k, varies with temperature and within the range of biologically acceptable temperatures, about doubles for each 10° C rise. In aerobic processes, a large portion of the organic waste is converted to biological cells so that Y is high. Here, θ_c^m is only a fraction of a day. In anaerobic processes, on the other hand, only a fraction of energy contained in organic matter is available for microbiological growth so that Y is quite small. For this case θ_c^m is several days.



·Figure 3. RELATION BETWEEN SOLIDS RETENTION TIME, EFFLUENT WASTE CONCENTRATION AND PROCESS EFFICIENCY

Table 1. Usual Range of Kinetic Coefficients For Aerobic and Anaerobic Treatment Processes

Coefficient	Units	Aerobic	Anaerobic
Y	lb vol suspended solids/lb BOD_L	0.3-0.4	0.03-0.15*
b	day^{-1}	0.02-0.06	0.01-0.04
K_s	mg/l	1-50	20-300
k	lb BOD_L/day/lb vol suspended solids	4-24	4-20
θ_c^m	days	0.1-0.3	2-6

*For anaerobic systems Y is 0.03-0.05 for protein and fatty acid wastes and 0.14-0.16 for carbohydrate wastes.

Both substrate removal velocity, $(dF/dt)/X$ and solids retention time, θ_c. can be used as basic parameters in the design and control of all biological treatment systems (2). The former has received most attention for the aerobic treatment of organic wastes, while the latter is more widely used for anaerobic processes and for the control of nitrification in aerobic processes. The solids retention time has certain distinct advantages for biological processes in general. With this parameter, the concentration of active microorganisms present does not have to be known. For example if it were desired to maintain a θ_c of 5 days, this could be done by removing 20 percent of the total suspended solids from the system every day. By doing this 20 percent of the active microorganisms are also removed.

To use the concept of substrate removal velocity, however, the quantity of active microorganisms in the system must be known or estimated. A fair approximation to the active microorganism concentration is given by the mixed liquor suspended solids concentration in activated sludge systems so that the parameter can be reasonably well applied. However, in anaerobic processes or with nitrification, the concentration of active organisms is very difficult to determine so that the loading velocity concept is not easily applied.

Excess Sludge Production

A necessary by-product of all biological unit processes is excess sludge. Such sludge must be removed periodically from the treatment process and disposed by some means. This is frequently one of the most difficult and expensive operations associated with biological treatment. The quantity of sludge will vary with the type of biological treatment, whether aerobic or anaerobic, and with the method of operation, whether at long θ_c or short θ_c. Excess sludge is composed of two major fractions, (1) the excess microorganisms produced during waste treatment, and (2) the relatively stable organic suspended solids contained in the raw waste which are not altered by the treatment process, but which settle in tanks and are removed along with the excess biological cells. Excess sludge may be estimated as follows:

$$dX_s/dt = dX/dt + dX_i/dt \tag{8}$$

where:

dX_s/dt = Excess pounds of volatile sludge solids produced per day,

dX/dt = Excess microorganisms produced per day,

dX_i/dt = Stable organic suspended solids contributed by raw waste per day.

The excess microorganisms (dX/dt) can be estimated from Equation 1. The relation between excess microorganisms and θ_c^m or substrate velocity can be found by combinations of Equations 1 and 5:

$$\frac{dX}{dt} = Y \ \frac{dF}{dt} - b \ \theta_c \ \frac{dX}{dt} = \frac{a(dF/dt)}{1 + b\theta_c} \tag{9}$$

or,

$$\frac{dX}{dt} = \ (Y \ \frac{dF/dt}{X} - b)X \tag{10}$$

The value for dX_i/dt varies with the type of waste. In raw domestic wastewater, about 30 to 60 percent of the volatile suspended solids are relatively stable. Thus, this fraction would represent the solids to consider in evaluating the stable volatile suspended solids for this waste. Food processing wastes on the other hand, differ considerably and dX_i/dt may vary from zero for wastes containing no suspended solids, to a very large number for wastes with large quantities of suspended solids.

Nutrient Requirements

The proper operation of biological waste treatment processes depends upon the presence of sufficient inorganic nutrients for biological growth. With food processing wastes, the major nutrients which may be lacking are nitrogen and phosphorus. The quantity of each required can be estimated from the weight of biological cells produced per day and the proportion of nitrogen and phosphorus which they contain. The nitrogen and phosphorus content of bacterial cells is relatively constant for all biological processes and equals about 12 percent for nitrogen and 2 percent for phosphorus. Thus, the requirements for nitrogen and phosphorus can be evaluated as follows:

$$N = 0.12 \ (dX/dt) \tag{11}$$

$$P = 0.02 \ (dX/dt) \tag{12}$$

where:

N = pounds of nitrogen/day required

P = pounds of phosphorus/day required

dX/dt = excess microorganisms produced per day in pounds of volatile solids.

Air Requirements and Methane Production

The basic equations presented can also be used to evaluate the quantity of air required for an aerobic biological process or to evaluate the quantity of methane produced in an anaerobic process. When waste is consumed biologically in an aerobic process, a portion is oxidized, thus consuming oxygen. Oxygen is also consumed during decay of microorganisms under aerobic conditions. From these considerations and from a materials balance using Equation 1, the oxygen required in waste oxidation can be determined from the following:

$$C = dF/dt - n(dX/dt)$$

or,

$$C = (1 - nY)(dF/dt) + nbX \qquad (13)$$

where C is the pounds of oxygen used per day and n is a conversion factor equal to the oxygen required to oxidize a unit mass of cells to inorganic end products. The value for n is generally close to 1.4 when Y is expressed in pounds of volatile suspended solids per pound of waste COD, X in pounds of volatile suspended solids, and dF/dt in pounds of COD consumed per day.

The oxygen requirement can also be expressed in terms of the solids retention time as follows, using units similar to those above:

$$C = \left(1 - \frac{nY}{1 + b\theta_c}\right) \frac{dF}{dt} \qquad (14)$$

During anaerobic treatment, the quantity of consumed waste not converted to biological solids is converted to methane gas. Equations similar to those for oxygen consumption in aerobic processes can be used for prediction of methane production in anaerobic processes, as follows:

$$M = m[(1 - nY)(dF/dt) + nbX)] \qquad (15)$$

Here, M is cubic feet of methane produced per day and m is a conversion factor which equals the methane equivalent of organic matter. For standard conditions of temperature and pressure m equals 5.6 cubic feet of methane per pound of COD (17). The other units in Equation 15 are the same as for Equations 13 and 14. Methane production as a function of solids retention time is as follows:

$$M = m\left(1 - \frac{nY}{1 + b\theta_c}\right) \frac{dF}{dt} \qquad (16)$$

The units in Equation 16 are the same as for Equation 15.

Safety Factor for Design

The failure point for aerobic biological treatment occurs at a solids retention time, θ_c^m, of about 0.2 days and for anaerobic systems, θ_c^m is about 3 days. In order to prevent process failure, longer solids retention times must be used in practice (2). Processes which are considered conventional and have stable operation and high efficiency of treatment normally are operated with solids retention times 10 to 70 times greater than θ_c^m. Processes which are high rate, on the other hand operate closer to the failure point, are in general less efficient, and require closer control. They generally employ safety factors in the range of 3 to 20. Processes designed for operation with little supervision or maintenance or designed for highly stable operation with low excess biological solids production generally have very high safety factors of 50 to 100 or more. These safety factors apply whether the process is aerobic, anaerobic, or designed for autotrophic reactions such as nitrification.

Processes designed and operated on the basis of substrate removal velocity can also be considered in terms of a safety factor. The usual maximum removal velocities for both aerobic and anaerobic systems based upon active organisms is 4 to 24 pounds of COD per day per pound of organisms. By applying the safety factors discussed above to reduce the applied removal velocities, typical values for high rate, conventional, and low rate systems can be obtained.

AEROBIC TREATMENT OF FOOD PROCESSING WASTES

Most of the papers presented at this National Symposium on Food Processing Wastes have been concerned with use of aerobic processes for treatment of food processing wastes. A summary of the various results reported will be made and will be compared with parameters outlined under the previous sections on principles of biological treatment.

Biological Growth Yield

The biological growth yield coefficient, Y, gives the portion of waste converted to biological solids. This term is important as it indicates both the quantity of biological solids which require disposal and the quantity of inorganic nutrients such as nitrogen and phosphorus required for treatment. As indicated in Table 1, the value for Y for aerobic systems in general is about 0.3 to 0.4 pounds per pound of BOD_L or COD consumed, which would equal about 0.4 to 0.6 pounds in terms of BOD_5 consumption values.

Esvelt (8) found values for Y of 0.46 - 0.57 for peach, pear, and apple wastes. Church (6) found a similar value even when fungi, rather than bacteria were used for treatment, suggesting the general validity of this range for all types of aerobic processes.

Guttormsen and Carlson (4) reported a high value for Y of about 1 pound of suspended solids per pound of BOD for potato processing wastes, but this was a combined value including not only biological solids, but digestible suspended solids in the influent.

The organism decay rate, b, is normally low, about 0.02 to 0.06 per day. This means that if left with no food, the microbial mass would decrease at a rate of 2 to 6 percent per day. Esvelt (8) reported an unusually high value of about 11 percent per day of 20° C for fruit packing wastes, but this dropped to the more normal lower values at reduced temperatures. At low loadings, the cell decay plays a significant part in reducing the total quantity of biological solids for disposal.

Substrate Removal Velocities

Maximum substrate removal velocities are about 4 to 24 pounds of BOD_L per day per pound of microbial mass, depending upon temperature. Streebin (9) was the only individual reporting operating values near this maximum with a loading of 4 to 6 pounds of COD per pound of mixed liquor volatile solids in the first stage of a two stage process for cannery wastes. However, without a second stage operating at a much lower loading and without the recycle scheme that was used, the process no doubt would have failed.

Most of the food processing waste treatment systems described were operated with conventional loadings of about 0.5 pounds of BOD_L per pound of mixed liquor volatile solids or less. Richter and Pailthorp (5) reported values of 0.1 to 0.4 for potato processing waste treatment, Graham and Filbert (7) indicated values of 0.03 to 0.42 for canning wastes combined with domestic wastes, Esvelt (8) stated 0.4 was used for fruit processing wastes, Jones (10) found values ranging from 0.014 to 0.38 with an average of 0.14 were satisfactory for citrus processing effluents, and Palmer (12) used comparable values ranging from 0.03 to 0.47 for cannery waste treatment. In almost all cases efficiencies of BOD removal of 90 percent or better were obtained.

Several of the above values are much below the normal value of 0.5 pounds of BOD per day per pound of solids and are typical of the low-loading values used for extended aeration systems. The lower loadings were generally used to reduce the biological solids production. This was indicated by Richter and Pailthorp (5), Graham and Filbert (7), Esvelt (8), Streebin (9), and Palmer (12).

Microbial Concentration

A significant conclusion which can be drawn from the concept of substrate removal velocity is that more waste can be treated per day in a given reactor by increasing the concentration of microorganisms or mixed liquor volatile solids. For a given removal velocity, the greater the mass of organisms the greater will be the quantity of waste which can be treated. This was well illustrated by Richter and Pailthorp (5) when they increased the mixed liquor suspended solids concentration to 4000 mg/l and by Palmer (12) who used mixed liquor suspended solids concentrations as high as 10,000 mg/l. In both cases volumetric loadings of 100 to 200 pounds of BOD per thousand cubic feet of aeration volume per day were obtained and with a high efficiency of treatment. Difficulties with maintaining such high concentrations, however, were emphasized. This is frequently true when attempts are made to maintain mixed liquor solids concentrations greater than about 2500 mg/l.

Aerated Lagoons

The general biological principles which apply to activated sludge treatment also apply to treatment in aerated lagoons. In a flow through system of this type without recirculation of active biological solids, the solids retention time is about equal to the hydraulic detention time. Thus, for conventional loadings using safety factors of 10 to 70, and with θ_c^m for aerobic systems of 0.2 days, hydraulic detention times of 2 to 14 days are indicated.

Since aerated lagoons are not usually designed for removal of the microorganisms developed during treatment, the effluent generally contains a high concentration of microbial solids which consume oxygen in the stream or BOD bottle during organism decay. For this reason, efficiency of treatment in aerated lagoons is seldom greater than 70 to 80 percent. Esvelt (8), for example found an efficiency of about 70 percent BOD removal for treatment of fruit processing wastes in aerated lagoons with a detention time of 5 to 10 days. Richter and Pailthorp (5) and Dostal and Burm (15) indicated similar experience with other fruit processing wastes treated in aerated lagoons.

ANAEROBIC TREATMENT OF FOOD PROCESSING WASTES

Food processing wastes generally have characteristics which should make them susceptible to anaerobic treatment. They generally have BOD concentrations within the desirable range of 1000 to 4000 mg/l. Many of the food processing wastes (exceptions are seafood (11) and meat processing wastes) have nitrogen and phosphorus concentrations which are low for aerobic treatment, but sufficient for the anaerobic process. A significant advantage of anaerobic treatment is that microbial production is low. Only about 10 to 20 percent of the BOD_L is converted to cells with carbohydrates, and only about 2 to 6 percent with protein or fatty acid containing wastes. Another characteristic of food processing wastes as pointed out by Palmer (12), Brenton and Fischer (13), Soderquist and Williamson (11), and others is the seasonal nature of the wastes, requiring a treatment process which can be brought to full operation within a very short period of time.

The anaerobic process has not been widely used for food processing waste treatment. Most anaerobic systems have been deep lagoons with results as described by Brenton and Fischer (13), Dostal and Burm (15), and Guttormsen and Carlson (4). In order to prevent washout of the sensitive methane bacteria, anaerobic lagoons should have detention times of 10 days or longer. Even then, contact with air would tend to limit the effectiveness of the anaerobic microflora. Also, odorous end products such as hydrogen sulfide may limit the application of an open lagoon system in urban areas. Dostal and Burm (15) mentioned the use of a floating styrofoam cover on an anaerobic pond for treatment of potato processing wastes which may serve to overcome some of the problems with anaerobic lagoons.

Anaerobic treatment of food processing wastes using high concentrations of microorganisms as in the activated sludge or trickling filter systems has been limited. The main usage has been for wastes from the meat packing and alcoholic beverage industries (17). Such systems, however, offer much promise for treating wastes with concentrations and temperatures typical of food processing wastes. The anaerobic process has been studied extensively over the past 15 years from a fundamental standpoint and is ready for wider usage. The process is not suitable for all wastes, but its limitations are well known. For those wastes which are susceptible to the process, the advantages are significant. The potential savings to the food processing industry should be sufficient to overcome the reluctance to assume the risk involved in the trial of a new method.

A relatively new anaerobic process called the anaerobic filter has been developed and has had several years of laboratory experimentation. At this time it appears to offer the most promise for treatment of wastes with BOD ranging from 500 to 6000 mg/l and at temperatures of 15° to 35° C.

The Anaerobic Filter

In Figure 4 is shown a schematic diagram of an anaerobic filter. Its operation has been described in detail previously (18). The filter consists of a bed of submerged media through which waste flows in an upward direction. The anaerobic microflora grow within the bed and either cling to the media or grow in the voids between. The filter has a large capacity for retaining microorganisms so that concentrations up to 20,000 mg/l are typical after a period of operation. Only a few types of media have been explored and one-inch rounded stone appears to be one of the best for use.

The effect of detention time on efficiency of treatment is illustrated in Figure 5 for operation at 25° C. With waste concentrations about 750 mg/l the efficiency of waste removal is a function of detention time. Experiments at other temperatures have indicated that effective treatment can be obtained at temperatures as low as 15° C, although the rates are much lower than at 25° C.

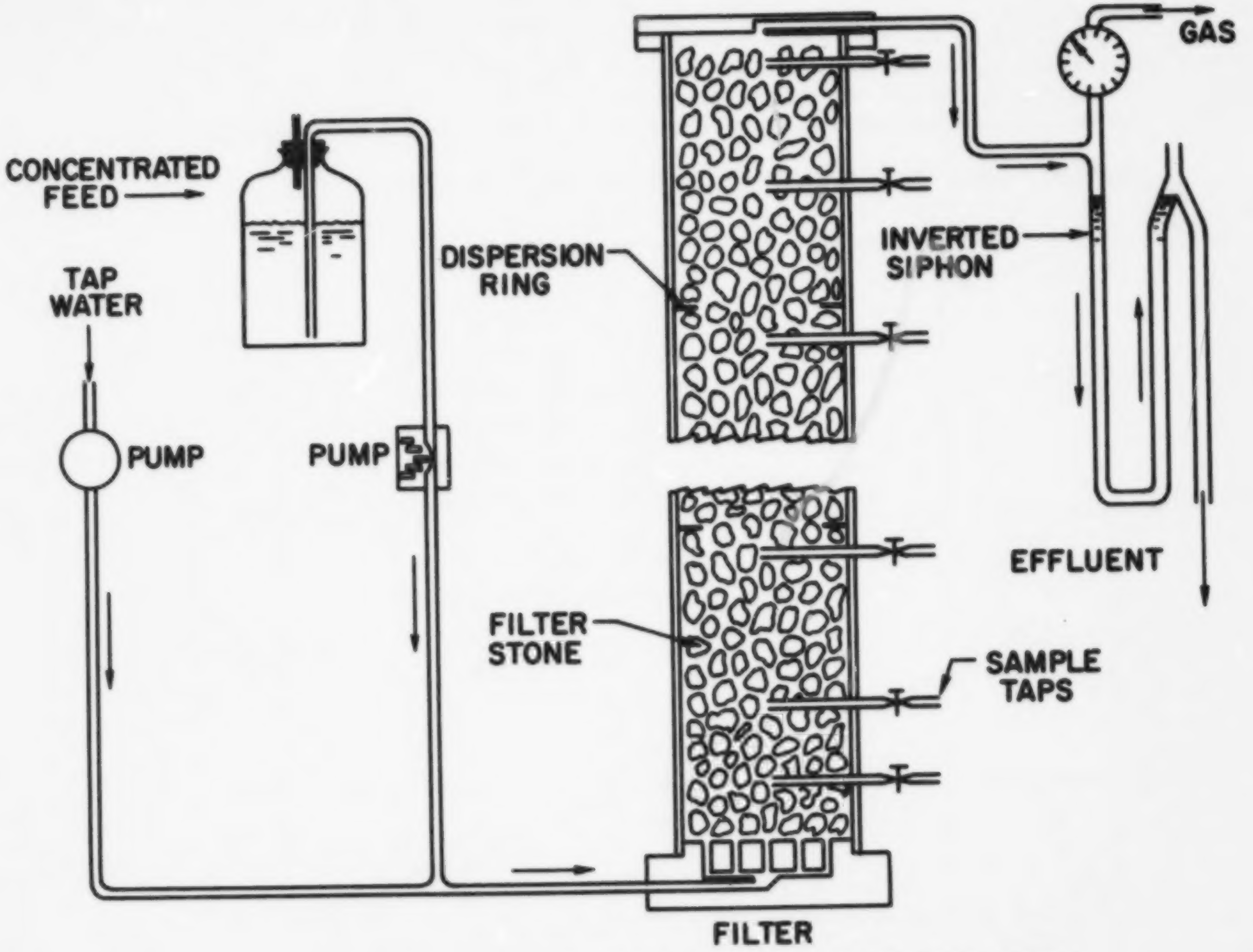

CONCENTRATED FEED
TAP WATER
PUMP
PUMP
DISPERSION RING
FILTER STONE
INVERTED SIPHON
GAS
EFFLUENT
SAMPLE TAPS
FILTER

Figure 4. SCHEMATIC DIAGRAM OF LABORATORY ANAEROBIC FILTER

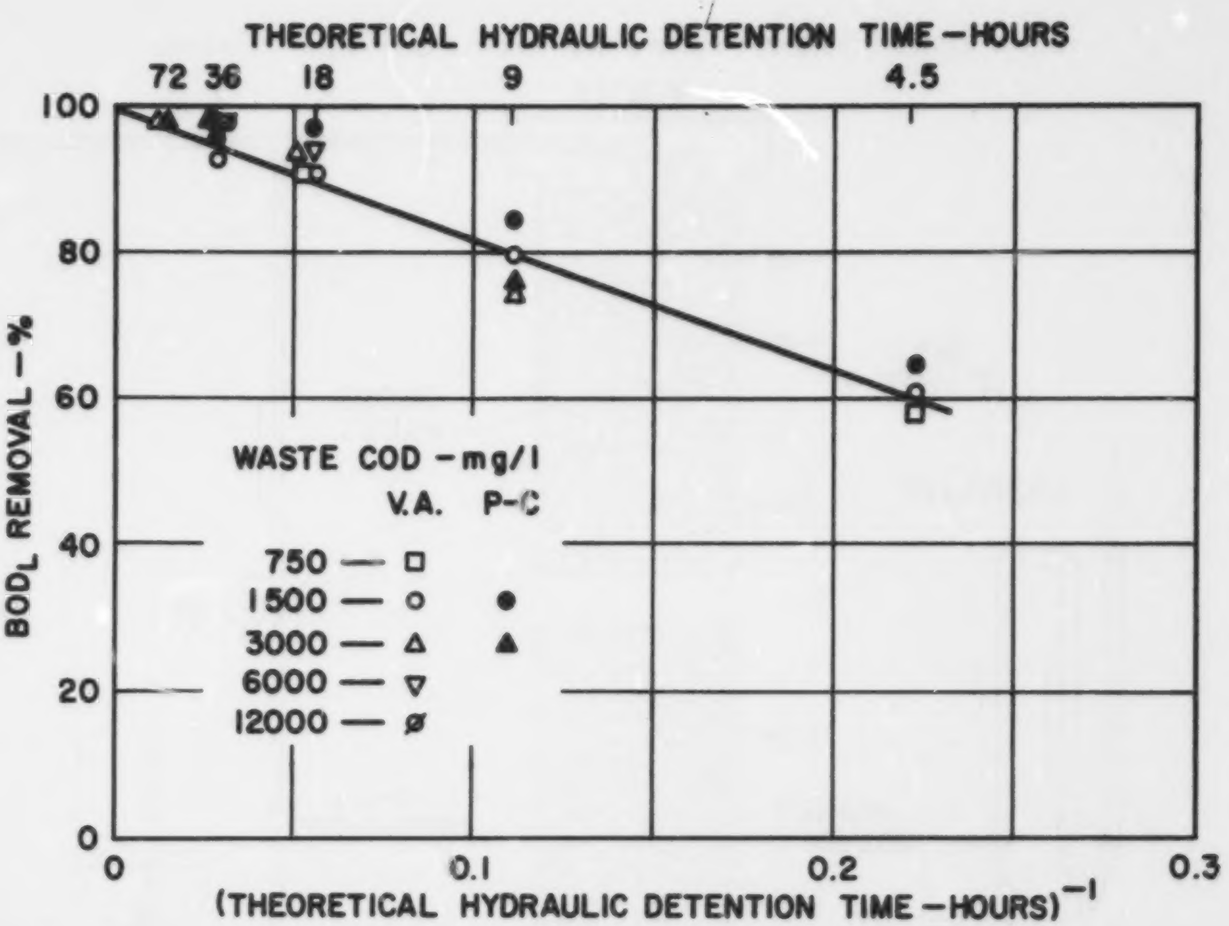


Figure 5. RELATION BETWEEN DETENTION TIME AND EFFICIENCY OF WASTE REMOVAL FOR DIFFERENT WASTE CONCENTRATIONS USING THE ANAEROBIC FILTER. V. A. represents an acetate-propionate containing waste and P-C represents a protein-carbohydrate containing waste (Young, J.C. and McCarty, P.L., "The Anaerobic Filter for Waste Treatment," Tech. Report No. 87, Civil Engineering Dept., Stanford University, March 1968).

The anaerobic filter is of simple design and requires no sludge or effluent recycle to maintain a high treatment efficiency. Unlike aerobic treatment processes, the anaerobic filter results in exceptionally low solids production. With low solids-producing wastes such as fatty acids and proteins, the filter can be operated for well over a year with no need for solids wasting. High carbohydrate containing wastes, however, produce more biological sludge and sludge wasting a few times a year may be necessary.

The filter responds rapidly to changing loads. It has an added significant advantage for food processing wastes in that it operates well on a periodic basis. Laboratory filters have been started immediately after receiving no waste for periods up to a year. The efficiency of treatment may be a little below normal for the first few days after a long period with no feed, but the normal efficiency is regained rapidly.

Their are certain limitations for the anaerobic filter which must be recognized. The efficiency of treatment may be less than shown in Figure 5 for wastes with concentrations less than about 500 mg/l. The filter operated best on soluble wastes which will not tend to clog the void spaces. Ways to eliminate this problem are currently under study. Control of pH is also necessary as the methane bacteria are sensitive to large variations. Wastes must have an alkalinity of at least 500 mg/l and preferably 2000 mg/l to avoid a significant pH drop during treatment. A high sulfate concentration presents some special problems. With sulfate concentration about 200 mg/l, the hydrogen sulfide produced under anaerobic conditions from sulfate reduction may be toxic to the methane forming bacteria. In addition, the hydrogen sulfide may produce an objectionable odor. Finally, the initial start-up of an anaerobic filter must be done carefully in order to establish the proper microflora.

With wastes which are susceptible to treatment by the anaerobic filter, significant advantages can be realized. Power requirements, maintenance, and excess biological solids production are very low. The filter operates exceptionally well under seasonal conditions of operation. Methane gas is a useful by-product. Many of the food processing wastes appear ideal for treatment by the anaerobic filter. Results of pilot plant studies for treatment of potato processing wastes by the anaerobic filter were reported by Guttormsen and Carlson (4). More studies on this scale or larger are needed to determine the overall feasibility of the process.

OTHER ASPECTS OF FOOD PROCESSING WASTE TREATMENT

The need for waste treatment represents somewhat of a failure, a failure to successfully use all components of the processed food. A desirable goal is complete utilization of all by-products and extensive reuse of process waters so that waste disposal is not necessary.

In accordance with the goal of by-product recovery, Church (6) reported on the use of fungi for waste treatment hoping to recover the mycelium for use as an animal food supplement. More basic research with fungi is desirable as they have long been recognized to be capable of consuming wastes that are not readily digestible by the bacteria normally used in waste treatment.

The use of waste activated sludge from food processing for animal feed has been suggested and would help considerably in the solids disposal problem.

Jones (10) indicated efforts to treat the effluent from citrus processing wastes to such a degree that the water could be reused. Although he felt the reprocessed water presently was not as inexpensive as raw water, the economics may change when effluent requirements become more rigid.

Some wastes from the food processing industry are not susceptible to biological treatment and chemical and/or physical methods must be used. Mercer, Maagdenberg, and Ralls (14) discussed the treatment of olive brine which was perhaps too saline for biological treatment. They used activated carbon to remove dissolved organics so that the brine could be reused rather than discharged to waterways. Technology for reclaiming spent carbon has advanced rapidly so that chemical and physical methods are reaching a competitive point with biological methods, especially when both organic and inorganic nutrient removal are being emphasized.

Gilde (16) suggested another approach in which the ground surface was used as a biological system. Waste was allowed to flow over the surface and was consumed by attached organisms. Nutrients were also removed and converted to hay, a usable by-product.

Another desirable direction for the food processing industry is to take the processing step directly to the field, or as Soderquist, Williamson, and Blanton (11) suggested, to the sea, and combine it with the harvesting step. Thus, the residuals from processing could be returned directly to the soil or the ocean to add to their enrichment. As the cost of waste disposal increases, initially unlikely solutions such as these may suddenly become attractive.

SUMMARY

The fundamentals of aerobic biological treatment are well understood and application in full scale has been sufficiently demonstrated and reported at this meeting and elsewhere. The fundamentals of anaerobic treatment are also well understood, but adequate field demonstration is still a required step. Biological treatment, however, is not the final answer. The public desire for cleaner water and the new and promised government regulations resulting from this desire no doubt will give the proper incentives so that in the future the more desirable reduction of waste quantities and improvement in the efficiency of product recovery will be achieved to a high degree by the food growing and processing industry.

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WURDD'S TASK FORCE ON AGRICULTURAL POLLUTION

by

J. Peter Clark[1]

One of the first acts of Dr. Arthur I. Morgan, Jr., upon becoming the new director of the Western Utilization Research and Development Division of the U.S. Department of Agriculture, was to create a special Task Force on Agricultural Pollution. I was made chairman of this group, which came to consist of about fifteen scientists from various disciplines and commodity specialties. After numerous meetings, we evolved both a plan of action and a number of specific research suggestions. This paper is a brief discussion of these two areas of accomplishment. Also, it is a general introduction to some of the other pollution-related research conducted at our Division.

Process Modifications vs Waste Treatment

We have come to believe that modifying food processes is a most promising approach to reducing pollution from agriculture. The classic examples, discussed in greater detail in other reports, are Dry Caustic Peeling of Potatoes (Graham, Smith*) and In-Field Processing of Tomatoes (Wagner). In both cases, not only is the waste quantity reduced but product yields are also increased. It should be obvious that any increase in yield must reduce the potential quantity of waste. Yet many food processes remain unchanged, out of tradition or for lack of attention, or, perhaps, because the benefits of change have not been made sufficiently impressive. It is only relatively recently that waste disposal and pollution control have demanded attention so aggressively from the processor. In response to such a demand, it is normally convenient to consider forms of biological treatment. But, as various studies by the FWQA have shown, biological treatment of food wastes in the volume frequently encountered demands enormous capital investment and unpleasantly high operating expenses. Thus may be provided the required incentive for studying food processes carefully and for adopting new processes that reduce wastes and improve yields.

One of the ways yields can be improved is to produce new products such as animal feeds, chemicals, or building materials along with the original primary product. In this area, our Division is doing research on the conversion of both cellulosic and leafy plant wastes to animal feeds (Kohler). Also, we have sponsored an investigation of various uses for rice hulls (Staackmann).

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*References are to other papers presented at the National Symposium on Food Processing Wastes.

Frequently the necessary modifications are not very sophisticated, but yet quite effective; the experience of Artichoke Industries in Castroville is a good illustration (Perkins).

The examples I have cited represent on-going, rather large projects for the most part, with which the Task Force has had little direct connection. On the other hand the Task Force is looking carefully for new opportunities for the same sort of discoveries. For example, blanching is recognized as a major source of water pollution in freezing operations. It may be that new forms of heat transfer using gases, recycled liquids, or perhaps microwave energy can be justified by a reduction in waste water. Or, more exciting, new approaches to freezing using protective chemicals may eliminate the need for blanching while improving product quality.

Another process we feel could stand examination is the conversion of feed into meat and manure in the factory we call a cow. With concentrated animal feeding threatened by water quality control restrictions, the volume and properties of wastes produced by a given feed mix may be as critical as the animal weight gain in optimizing feed lot operations.

In other divisions of the USDA, concepts have appeared which we seek to apply to new situations. For example, our Weslaco, Texas, laboratory has made pureed drink concentrates from whole citrus fruit, greatly reducing the waste produced. Perhaps other commodities can be used with less peeling or trimming than at present.

Many agricultural commodities rely on strong salt brines for processing. We have learned how to reuse olive brine by treating it with charcoal (Ralls) and we have also investigated processing leather tanning brines. The pure culture fermentation process for pickles developed by our Southern Laboratory permits packing the brine instead of throwing it away. Perhaps other commodities can also be packed in their associated process liquids, for example, fruits in their own sugars, as pineapple often is.

The opportunities for process modification are clearly very broad. The general principles seem to be: minimize water use, recycle water or other liquids where possible, put as much of the raw material into the final product as possible, and make salable material from whatever cannot go in the primary product.

Other Research Problems

One of the major difficulties of evaluating a waste stream for either treatment or value recovery is the lack of a rational means of expressing the composition of the stream and the relationship of the stream to its environment. A good illustration of the inadequacy of current measurements, such as BOD, COD, TDS, SS, etc., is the waste stream from olive processing. This strong salt brine is a serious pollutant in the Central Valley of California, but it probably would not be so along the Pacific Ocean. There is clearly a need for some practical representation of the interaction of a given stream with its environment—that is, a kind of quantitative ecology.

Still another difficulty with traditional measurements is their presumption that a given stream is a waste and should be reduced to innocuous CO_2 and H_2O. This is why the biological or chemical oxygen demand is a frequent measurement. But if a waste stream is to yield biological or chemical value, then some nutritional property or chemical analysis is a more meaningful measurement. There is a certain psychological benefit in referring to a dilute sugar stream in terms of its caloric content, for example, instead of its tendency to putrify. One would like to recover calories, but would dispose of putrification.

On a more practical level than analysis or "psychology," the Task Force has examined a number of diverse potential research problems in the pollution area. One example is uses for the Uni-flow Filter (Popper) which we see as an important solid-liquid separation device. Many conventional waste treatment processes have serious sludge handling problems which may be amenable to this new approach.

Sometimes we look at a specific waste problem and then expand our consideration. At one time the waste from some castor oil production was thought to be toxic to all animals. We found that fish could live well on castor pomace that was toxic to warm blooded creatures. Now, the castor meal produced in this country usually is not toxic because of the treatment it normally receives, but the tolerance of the fish to the poison does provide a margin of safety which thus creates a possible new use for this material. Castor is not the only potential source of nutritious fish feed so we are now doing research in the general area of fish culture. We are learning about both catfish and carp, their nutritional requirements, habits, diseases, and other cultural needs.

Our Laboratory has a wide background in enzyme technology and so we are looking at the possibility of growing useful enzymes on waste streams and also at the use of enzymes to convert or treat waste streams. As a side issue, we have become concerned about the potential health hazards of widespread use of enzymes and are trying to learn whether the enzyme itself or some impurity may be responsible for allergic reactions.

We started looking for a way to clean up the waste stream from wool scouring and are now trying to find a better way to clean raw wool while recovering lanolin for sale.

We have discussed uses for whey, the largest food processing waste in this country, and have tried to find alternatives to the solid waste disposal problems created by commodity diversion under various marketing orders. We have unfortunately not had any bright ideas in either area so far, but they illustrate the breadth of topics considered by the Task Force.

Basically, the Task Force on Agricultural Pollution is a new form of organization intended to develop research ideas and to sponsor new projects until they are absorbed by our commodity research groups. By mixing scientific disciplines in an informal, non-critical atmosphere we have promoted imaginative and perceptive ideas which we hope will lead, someday, to successful ventures comparable to dry caustic peeling and others recently reported.

IN-FIELD PROCESSING OF TOMATOES

by

Joseph R. Wagner[1]

Tomatoes are an important processing vegetable in the United States. From 5 to nearly 7 million tons of tomatoes have been delivered to our canneries per year. The State of California produces and processes approximately two-thirds of the national total. The industry in California is unique with regard to its dependence on machine harvesting; approximately 95 percent of the processing tomatoes delivered to canneries are now machine harvested.

The adoption of machine harvesting in California was accelerated by an acute shortage of field labor. However, it is now the cheapest and the only practical available method for harvesting the crop. It seems safe to assume that large scale production and machine harvesting of tomatoes will continue in California.

The growth of machine harvesting has had many effects on the industry, among which is the large amount of waste material. As now practiced, the crop is harvested in a single pass. The vines are cut at the base and lifted by the harvester for separation of fruit and vines. The vines and much of the cull fruit and dirt are dropped behind the harvester, and if the harvester is operated without a sorting crew the tomatoes may include 20 percent or more of dirt, trash and culls (1). Even under good operating conditions there is apt to be more damaged fruit than commonly encountered in hand picked tomatoes. A crew of sorters usually rides the machine to remove and return to the field culls, trash, and dirt. Sorting on a moving harvester is a hard, unpopular job. Even with a large sorting crew it is impossible to achieve complete separation on the harvester. Much of the fruit damage may go undetected, and later contributes materially to spoilage during long hauls to canneries and other delays prior to processing (1). Collectively the dirt, trash, and cull tomatoes, regardless of cause, create a serious waste disposal and sanitation problem at the cannery.

Industry concern over the difficulty of assuring the quality of raw fruit delivered to the cannery has lead to the investigation of in-field washing and sorting stations. The location of sorting, cleaning and sanitizing facilities in the immediate harvest area offers important potential advantages. Rejected raw product, trash, field soil, and product wash water would remain in the field. Waste disposal there can be by simpler methods and at less cost than at a central plant in an urban community. Unfortunately, this system also has flaws.

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[1] Chief, Vegetable Laboratory, Western Utilization Research and Development Division, ARS, USDA, Albany, California.

Studies conducted in recent years by the tomato processors, the National Canners Association (NCA) and the University of California indicate that elimination of dirt, trash and culls at the in-field stations is quite feasible (1-4). However, the handling and washing causes additional damage to the ripe fruit. The sorted, washed fruit is very vulnerable to mold and other types of in-transit and holding losses. Therefore a considerable portion (10 to 20 percent) of the clean, ripe fruit collected from a washing station may spoil in the period required to deliver it to a distant processing line. To the loss represented by the value of the spoiled fruit one must add the costs of transportation and additional waste disposal.

The industry now recognizes the potential advantages of processing these clean, washed and highly perishable tomatoes before large in-transit and holding losses can occur. Processing tomatoes in the rural harvesting areas should reduce the total amount of waste and increase the yield of processed products per ton of tomatoes harvested. Thus, virtually all of the solid and liquid wastes derived from the preparation of tomato juice and concentrates would be retained in the harvest area. Only liquid product from such preprocessing operations would be transported to urban areas where plants exist. Such an in-field preprocessing station would include the facilities of a sorting and washing station plus those for crushing the clean tomatoes, heating of macerates and pulping to separate the juice from the cores, skins and seeds. Evaporative cooling of the juice or partial concentration or acidification during preprocessing are all possible methods for stabilizing the liquid product for transporting to a central plant for final processing and packing. At least two large tomato processing firms have investigated field processing. However, their data are not available and we cannot effectively comment on their experience.

During 1969 a novel field research and demonstration tomato processing unit was built at Albany and operated at the Anzac Sorters station near Dixon, California by engineers and chemists of the Western Regional Research Laboratory.

Our unit combined the concept of field processing with the application of a new acidified tomato juice extraction process developed at our Laboratory for the production of tomato products of very high consistency (5-7). The adaptation of the acid extraction process to our field studies is now referred to as the Acidified-Field-Break process.

The field unit consists of three mobile components: The process line mounted on a large flat-bed trailer, a portable steam boiler, and an air-conditioned laboratory. The processing unit performs the following major steps:

(1) Preparation of tomatoes by washing and inspection.

(2) A hot-break for rapid enzyme destruction by heat within seconds after crushing the tomatoes.

(3) The optional acid treatment; the addition of acid to maximize extraction and product consistency and subsequent neutralization of added acid (either before or after pulping).

(4) Pulping to separate pulp from seeds, skins and fiber.

(5) Cooling and deaeration.

Additional detail on the process line is shown schematically in Figure 1 (8).

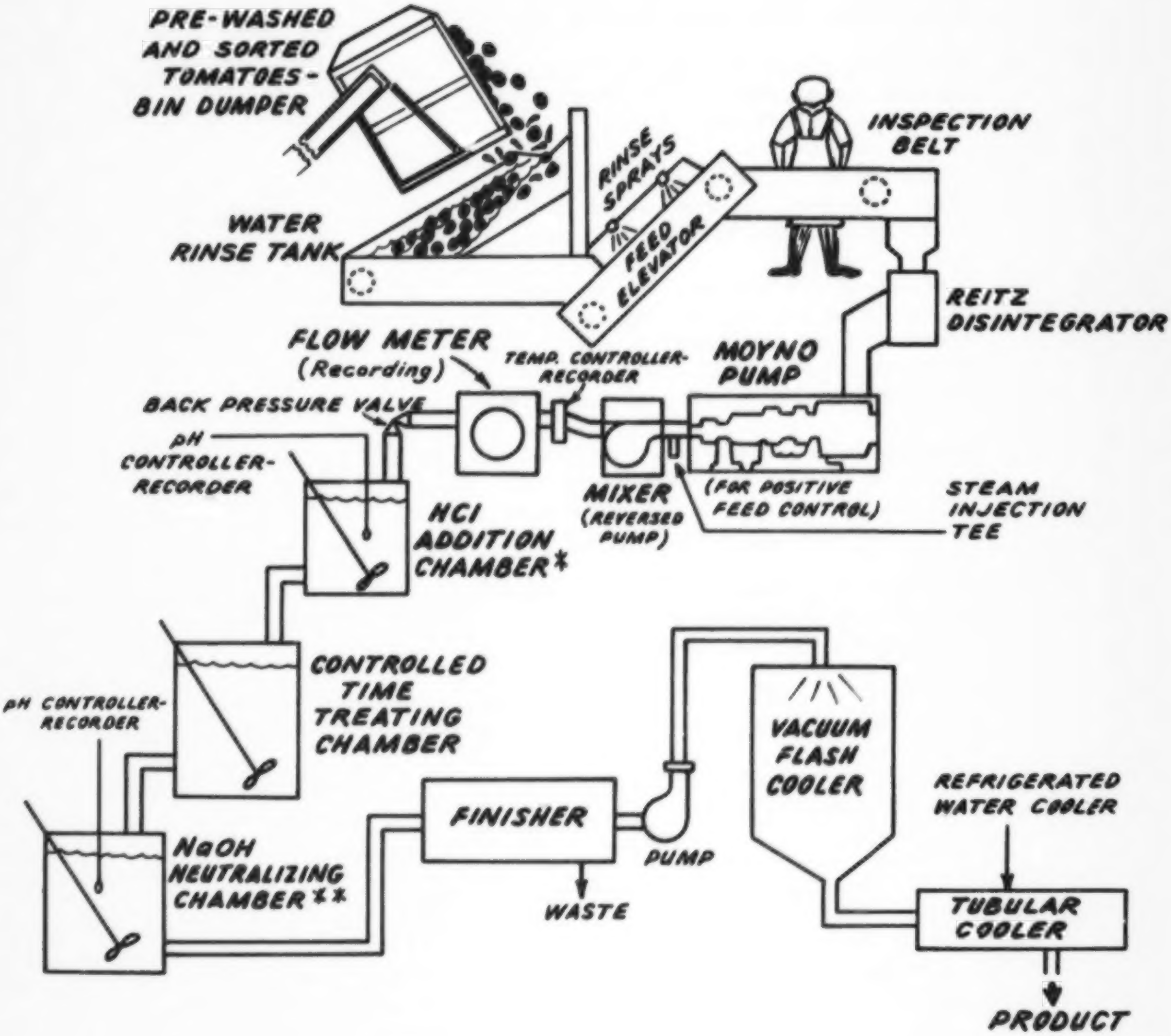
The unit was operated at Dixon from early August through the first week of October. Washed and sorted tomatoes were obtained from the nearby sorting and washing station. In a number of holding experiments comparisons were made between tomatoes processed within 2 to 4 hours after delivery and tomatoes processed 24 hours later. It was found that holding firm ripe tomatoes in bins at ambient temperature even without hauling resulted in a 6 percent increase in culls unfit for processing. Under similar conditions, 12 percent of soft, fully ripe tomatoes were rejected after holding for 24 hours. Therefore, prompt processing resulted in 6 to 12 percent increases in product yield in these experiments. These yield increases should be largely attributed to the advantage of a field location which favors prompt processing and minimization of handling damage.

When macerated tomatoes were processed with heat and the acid extraction treatment, 4 percent more solids were recovered from raw tomatoes than when heating only was used. This effect should result in an equivalent increase in product case yield per ton of tomatoes processed for manufacturers of concentrated tomato products. The increase in yield is confirmed by the reduction in weight of tomato pomace. The more complete transfer of soft tissue from the pomace fraction to the juice fraction results in a drier pomace, which should be easier to dehydrate for conversion to animal feed. In our studies the pomace, culls, leaves, stems, and other solid wastes were disposed of on nearby farm lands. Wash water was also returned to the land.

Juice would be the only material transported to a central plant. For stability in the transportation period, the product should be cooled. To obtain sufficient stability, products at natural pH (approx. 4.4) should be chilled to 40°F. If neutralization is postponed until delivery to the final processing point, product prepared at pH 2.75 can be held up to 24 hours at 70°F. without significant deterioration from microbiological action or loss of physical attributes such as color and consistency.

In closing, it seems appropriate to identify the people who contributed extensively to the project: The acid extraction process was originally developed by a group of chemists from our Laboratory headed by chemist J. C. Miers. In 1969 the process was scaled up to field operations under the leadership of engineer R. P. Graham. The unit was designed by engineer W. G. Schultz, who subsequently supervised the field operations in collaboration with Mr. Miers. Others who contributed to the success of the project were engineers J. L. Bomben and W. C. Rockwell and chemists M.-D. Nutting, D. W. Sanshuck, W. C. Dietrich, R. Becker, and H. J. Neumann.

PROCESS LINE


PRE-WASHED AND SORTED TOMATOES - BIN DUMPER
WATER RINSE TANK
RINSE SPRAYS
FEED ELEVATOR
INSPECTION BELT
REITZ DISINTEGRATOR
FLOW METER (Recording)
TEMP. CONTROLLER-RECORDER
MOYNO PUMP
BACK PRESSURE VALVE
pH CONTROLLER-RECORDER
HCl ADDITION CHAMBER*
MIXER (REVERSED PUMP)
(FOR POSITIVE FEED CONTROL)
STEAM INJECTION TEE
CONTROLLED TIME TREATING CHAMBER
pH CONTROLLER-RECORDER
NaOH NEUTRALIZING CHAMBER**
FINISHER
WASTE
PUMP
VACUUM FLASH COOLER
REFRIGERATED WATER COOLER
TUBULAR COOLER
PRODUCT

* *Acid treating and Neutralizing steps optional.*

** *Optional...... Juice may be transported in acid condition.*

Figure 1

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8. Figure 1 was part of press release #302-9-69, September 25, 1969, from this Laboratory.

A 16-mm color film was shown during the presentation to illustrate a typical field harvesting situation, the operation of the field processing unit, the reductions in wastes, the normal post-harvest cultivation of tomato fields, which offers a convenient route for field disposal of culls and debris, and the proposed utilization of cooling and other waste waters. The film is available on a loan basis from the Engineering and Development Laboratory, Western Utilization Research and Development Division, Agricultural Research Service, USDA, 800 Buchanan Street, Albany, California 94710. The film runs 13 minutes.

"DRY" CAUSTIC PEELING OF VEGETABLES AND FRUITS

by

Robert P. Graham[1]

The peeling of vegetables and fruits has long been a source of pollution in the processing industry. Hydraulic procedures to remove softened peel after lye or steam treatment have been customary. Present-day rulings regarding pollution, however, have led to a search for alternate methods of peel removal.

At the Western Regional Research Laboratory of the United States Department of Agriculture we have studied various methods of peeling vegetables and fruits to reduce the amount of peel waste which enters plant effluents. Such methods must also be economically feasible. It was recognized that some method of removing peel without the use of water would be desirable. Also, the procedure should work acceptably on both fresh and stored produce.

White Potatoes

Our initial efforts were directed toward white potatoes because of the large amount of peel loss involved. The procedure developed was called "dry" caustic peeling. We tried various methods of abrading the peel material from the potatoes after treating them with hot lye. Early tests on single potatoes impaled on a spit showed that the potatoes could be peeled with a dry brushing action using nylon brushes or flexible rubber-tipped brushes. This process was made more effective by heating the lye-treated potatoes with infrared heaters prior to brushing. Heating with steam and hot air did not produce the same results. It was also noted that if the lye-dipped potato was held for a period of time after dipping the effect of the infrared heating was enhanced and less caustic was required.

To study the technique further, experimental equipment with a capacity of about 500 pounds per hour was built. The first peeling device consisted of a single rubber-tipped roller. While this single-roll unit further encouraged our use of rubber-tipped rolls as a peeling medium, it had too many limitations. Two other peeling devices were built with different configurations to get a unit that would continuously handle potatoes in a small pilot plant. Both of these devices worked, provided the tip speed of the rolls was sufficient to make them self-cleaning.

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[1] Chief, Engineering and Development Laboratory, Western Utilization Research and Development Division, Agricultural Research Service, United States Department of Agriculture, Albany, California.

A forty-inch diameter barrel was used to turn the potatoes while they were being irradiated. The barrel, after several modifications, provided continuous operation. A 500-pound per hour pilot plant was then built to permit experimentation on potatoes stored for varying lengths of time and to provide enough peel material for examination. Because the potatoes were partially peeled in the barrel, two different waste products were produced, one essentially dry and the other with about 25% solids content.

This plant demonstrated the general feasibility of the "dry" caustic peeling procedure, especially as the amount of peel removed could be controlled by caustic dip time. It did, however, have several rather serious limitations. First, scaling up the barrel presented some serious difficulties, and second, residence time in the barrel was not uniform, since it depended on the shape of the potato. To overcome these difficulties a live-roller conveyor was tried. This is the type of equipment used for tomato inspection. When fitted with infrared burners it provided continuous turning of the potatoes and positive control of residence time under the burners. With this system almost all of the peel material was removed at one time, as only a small amount of the peel stuck to the rollers. Also, this unit used only 1/4 to 1/2 as much gas as the barrel. The amount of peel removed could be controlled by the caustic dip time and could be compensated when desired by control of the irradiation time. Potatoes leaving the peeler had a small amount of sticky residue not removed by the rubber-tipped rollers. This was removed by brushes with a small amount of water.

Peeling potatoes under proper conditions does not produce any significant heat ring. The potatoes do tend to darken sooner than potatoes peeled in the conventional system, but this can be prevented by a sulfite dip after peeling.

Further work done on this system was carried out with commercial-size equipment manufactured by Magnuson Engineers.

Sweet Potatoes

Some tests have been made on sweet potatoes, both on individual potatoes and on potatoes in modified commercial-size machines. The peeling loss for sweet potatoes is usually larger than for white potatoes. Most of the peeled sweet potatoes are cut into about 1-inch thick pieces and are canned. The potatoes for this purpose should have a smooth surface so that when they are autoclaved none of the potato will sluff off into the syrup. Sweet potatoes after washing are usually preheated in hot water and then immersed in about 20% hot caustic for 2 to 3 minutes. Peeling conditions are similar to those for white potatoes except that the brushing state following the stud rubber peeler is somewhat more critical.

Fruit

At the Western Laboratory we are now studying the "dry" caustic peeling of fruits for canning. A caustic dip similar to that used for conventional peeling with water sprays is used. The infrared heaters are not used because the heat from the burners tends to bake the peel on the fruit rather than let it soften.

Cling peaches are cut in half, pitted, and placed cup down on a mesh belt. Boiling 3% caustic is cascaded over the fruit for 5 to 10 seconds followed by a 10 to 15 second drain in a warm humid atmosphere. The fruit is then run through a rotating rubber disk peeler to wipe off the softened peel. The 1/32-inch rubber disks are stiffened by metal side disks which allow the peach halves to turn over but not drop through the rotors. The peeler as shown is mounted at a 45 degree angle and the fruit flows down against the rotation of the disks. We have also operated the unit in a nearly horizontal position so that the fruit is peeled as it is being conveyed along the peeler. Peeling losses are 4 to 5%, which is comparable to the loss when water sprays are used for peeling. Whole apricots, freestone peaches, and Bartlett pears have been peeled on the disk peeler. When peeling ripe pears the edges of the disks tended to mark the soft pear flesh, especially on the neck of the pear. This marking was reduced by cementing 1/8-inch diameter rubber tubing on the edge of the disks.

A 12-inch wide by 10-foot long model of the rubber disk peeler will be tested during the 1970 canning season in a local cannery.

In conclusion, at the Western Regional Research Laboratory of the United States Department of Agriculture we have attempted to attack pollution caused by vegetable and fruit peeling through process modification. We have attempted where possible to keep the peel materials from ever entering the plant effluent. In the case of the peeling of white potatoes we feel that this procedure will also result in economies in excess of the savings through control of water pollution.

REFERENCES (Showing Pictures of the Process)

1. Graham, R. P., Huxsoll, C. C., Hart, M. R., Weaver, M. L. and Morgan, A. I., Jr., "'Dry' Caustic Peeling of Potatoes," Food Technology, 23:2, 61 ff, (1969).

2. Graham, R. P., Huxsoll, C. C., Hart, M. R., Weaver, M. L. and Morgan, A. I., Jr., "Prevents Potato Peel Pollution," Food Engineering, 41(6), 91-93, (1969).

PILOT PLANT EXPERIENCE OF USDA-MAGNUSON DRY CAUSTIC PEELING PROCESS

by

Traver J. Smith[1]

In 1968, the Western Regional Research Laboratory had successfully experimented with peeling white potatoes utilizing infrared radiation to accelerate caustic destruction of the skin, followed by wiping off the softened peel with stud rubber rolls. We could see a potential application of our MAGNUPEELER in this process and about the same time we acquired a basic patent on an infrared-caustic peeling method which had been issued to Mr. Miles Willard, a well known food processing consultant. Consequently, we entered into a cooperative agreement with the Potato Processors of Idaho (a trade association) and the Western Regional Research Laboratory to construct a pilot line for commercial production tests on the application of Dry Caustic Peeling to white potatoes. The Idaho Processors furnished the standard portions of the line, Magnuson provided three new machines especially for the Dry Caustic Process, and the Laboratory provided technical supervision.

The pilot line was set up in parallel with a conventional caustic peeling line at the Aberdeen, Idaho, plant of Western Farmers Association. Potatoes were diverted just ahead of the commercial process, run through the Dry Caustic Process and then mixed back with the commercially peeled potatoes. This permitted us to make precise comparisons between the two processes on identical potatoes.

The first unit in the pilot line was a small ferris wheel type conventional caustic dip unit. The potatoes were dipped in a 12% caustic solution for one minute, while in the conventional process they were dipped in 20% caustic for four minutes. Both caustic solutions were at a temperature of 170°F. The caustic consumption on the dry peel line was only about 20% to 30% of that used on the conventional line because of the more dilute solution and the shorter dip time.

Following the caustic dip, the potatoes were stacked 10 to 12 inches deep on a holding belt for 3 to 10 minutes (depending on their condition) to allow the caustic to penetrate a thin layer at the surface.

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[1] Vice President, Magnuson Engineers, Inc., San Jose, Calif.

After holding, the potatoes entered the Infrared Unit, the first of the new Magnuson machines. A SHUFFLO was used to deliver one row of potatoes at a time onto a roller conveyor which rotated them as they passed closely beneath gas-fired infrared burners. The infrared source was a porous ceramic material heated to a red hot 1650°F. All surfaces of the potatoes received remarkably uniform exposure to the infrared radiation. The effect of the infrared was to quickly activate the caustic to totally soften the thin surface layer without forming the heat ring which usually results from caustic peeling. The infrared exposure time was only about one minute.

For the next few seconds, the potatoes were passed through the MAGNUSCRUBBER. This is a rotating cylindrical cage of stud rubber rolls. The potatoes are tumbled through the cage, with their flow being regulated by a central screw conveyor. The stud rubber rolls are rapidly rotating in a planetary action to wipe off the softened peel and fling it away by centrifugal force. This material is collected on the inner surface of a rotating drum and wiped out at the bottom. The peel waste is a dark brown thick paste of 23 to 25% solids at pH 11. It is more concentrated than the potatoes, because of the surface evaporation which occurs during the infrared treatment. It can be conditioned for animal feeding.

Up to this point no water has been used in the process. The potatoes leave the MAGNUSCRUBBER with a thin coat of this tacky paste over their surface. This is removed by the MAGNUBRUSHER, the next machine in the process. It is a cylindrical brush washer and uses a small amount of water which can run into the existing plant waste system or can be blended with the peel waste. This will reduce the solids content of the peel waste to possibly 15%, but no waste water at all will be discharged from the process. After brushing, the potatoes are briefly dipped in a 0.5% solution of sodium bisulphite to fix the color. This is also frequently done in conventional caustic peeling, but it is essential in the Dry Caustic Peeling process because these potatoes have no heat ring.

Incidentally, many people are confused by the term "Dry Caustic Peeling," thinking that it somehow involves undissolved dry flake caustic. Consequently, we and the Laboratory have adopted the name "USDA-Magnuson Anti-Pollution Peeling System," and because that's so long, we usually call it "Infrared Caustic Peeling." The process is referred to by all three names in published literature.

The Infrared Caustic Peeling process definitely accomplishes the objective of keeping the peel waste out of the plant waste water. For a French fry plant this reduces the solids in the plant waste system by approximately 75%. In a flake or granule plant, where less peeling is required, the reduction is about 50%. This obviously is very beneficial to waste treatment requirements.

The water used in the Infrared process is only about 5% of that used in the conventional caustic peeling process and only about 8% to 10% of that used in a typical steam peeling plant. This is another tremendous benefit to waste treatment requirements.

The amount of peel waste produced is reduced by about one-third. This, of course, also reduces the peel waste handling problem, but more importantly, it substantially reduces the cost of peeling potatoes by increasing the product recovery.

Because of the absence of the heat ring and the reduced caustic consumption, the potatoes peeled by the infrared process are much whiter than those produced by the conventional caustic process and they do not have the customary slippery surface which is associated with caustic peeling. This is an obvious quality benefit. The infrared treatment also selectively softens dark areas of defect and they are more completely removed in the subsequent wiping processes. This reduces the amount of hand trimming required to finish the potatoes for processing, another quality benefit.

This process shows great promise in other product applications. For example, the Western Utilization Research Laboratory has done much experimental work with sweet potatoes, where processors face waste treatment problems similar to those of white potato processors. Here, too, the process successfully removes the peel without using water and keeps the peel waste out of the plant waste disposal system. A very acceptable, high quality, smoothly peeled sweet potato has been produced. We have had some most successful short tests with Magnuson commercial equipment on sweet potatoes and hope to have a commercial line operating soon.

Other products, including beets, carrots, onions, and some fruits, have been run experimentally in laboratories. At this point we are confident of commercial success with beets and carrots, while the other products are most promising, but require more development.

We would like to express our appreciation to the Western Utilization Research Laboratory and particularly to Mr. R. P. Graham, Dr. C. C. Huxsoll, Mr. M. R. Hart, Dr. M. L. Weaver, and Dr. A. I. Morgan, Jr., Director of the Laboratory. All of these men have been personally involved in the development of this process and we at Magnuson Engineers, Inc., recognize them for their help and cooperation.

POSSIBLE USES OF UNI-FLOW FILTER

by

Karel Popper[1]

Most effluents contain both suspended and dissolved solids and in very many such effluents the BOD load of the suspended material vastly exceeds that contributed by the solute.

The primary treatment task to be carried out with such material then is the removal of the solids from the water phase. By extension, one may be able in some effluents to bring about precipitation of some of the noxious materials so that their removal would also become possible. In some rather common instances the removal of the solids will make the liquid either valuable or reusable. A tool that will do the job at a very low investment cost and a low operation cost had therefore to be invented.

Figure 1 may help to explain the function of the unit. Sludge enters the top of the hose and flows in it downwards. The solids move to the bottom and the solution oozes out through the cloth. As we go on, the sludge in the bottom of the hose accumulates to an ever higher amount and compaction and when it reaches a satisfactory stage, is ejected.

While the function of the unit is to filter, that is to separate solids from liquids, it would be wrong to think of it in engineering terms of a filter. The principle, as I see it, is LOW PRESSURE. Low pressure, no filter cake. No filter cake, no flow interruption. It really is as simple as that. Just let the sludge seek its own merry way to the bottom of the tube both by gravity and with the assistance of flow.

Uni-Flow filter inlet is shown in Figure 2. The slurry enters the distributor and flows through the nipples into the individual hoses.

Figure 3 is the Uni-Flow filter bottom. The hoses fit into the sludge take-off nipples which are fitted into a divisor plate. The filtrate stays above the divisor plate whence it is piped away and the sludge moves through the nipples to the sludge collector cone.

An example of an effluent that never needs to be discharged is water softener regenerant.

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[1] Fruit Laboratory, Western Utilization Research and Development Division, ARS, USDA, Albany, California.

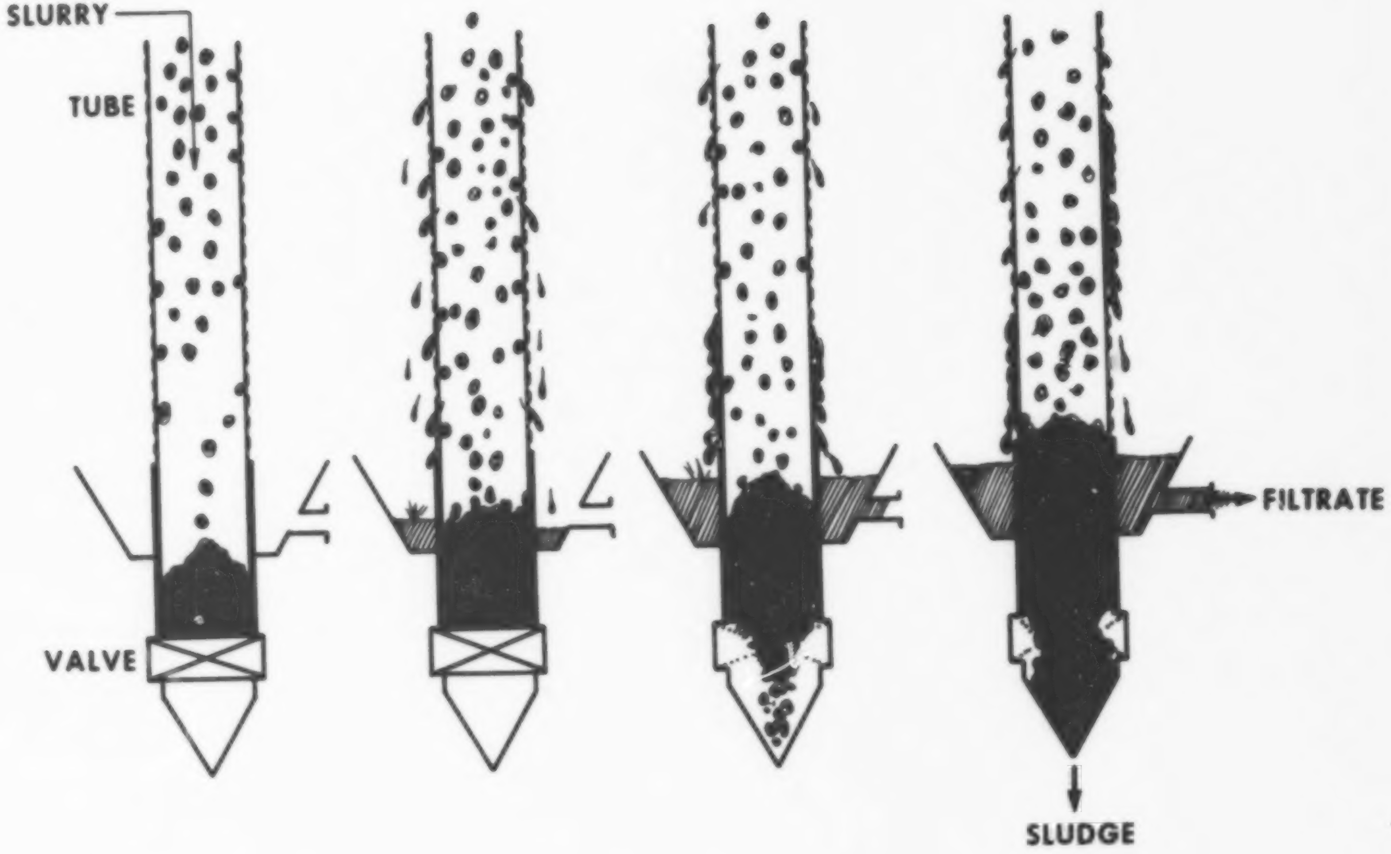
SLURRY
TUBE
VALVE
FILTRATE
SLUDGE

Figure 1

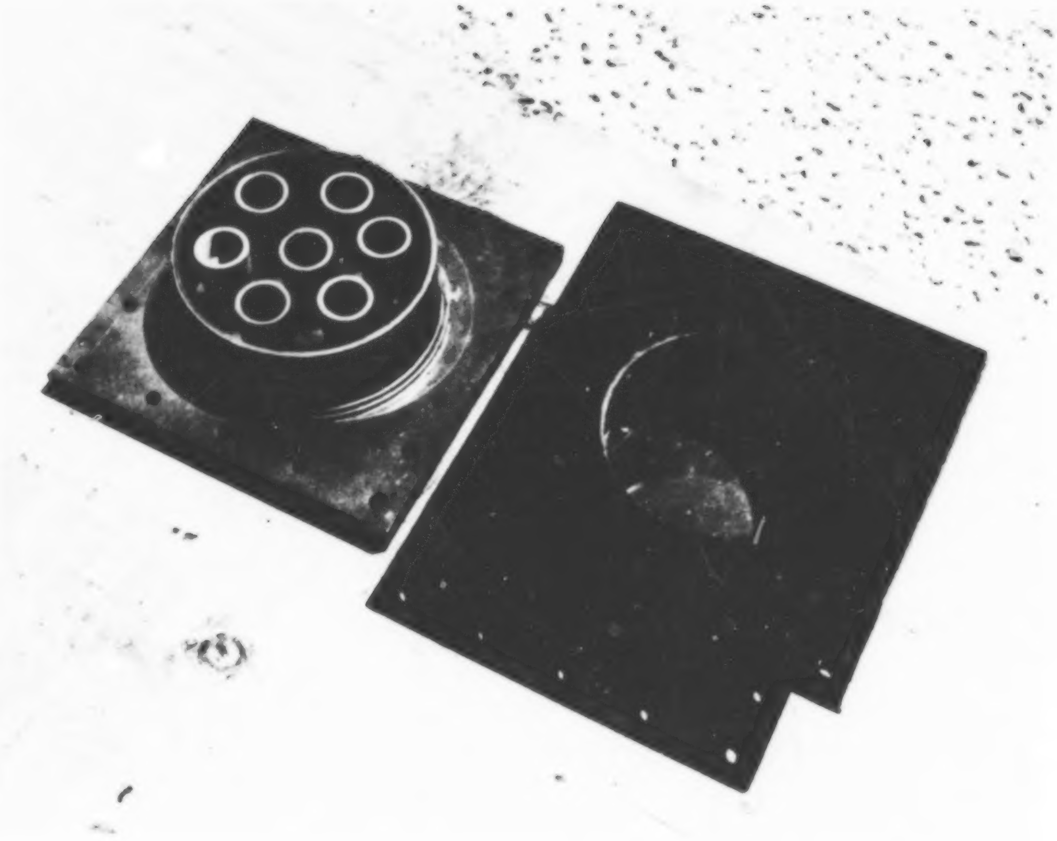

Figure 2.

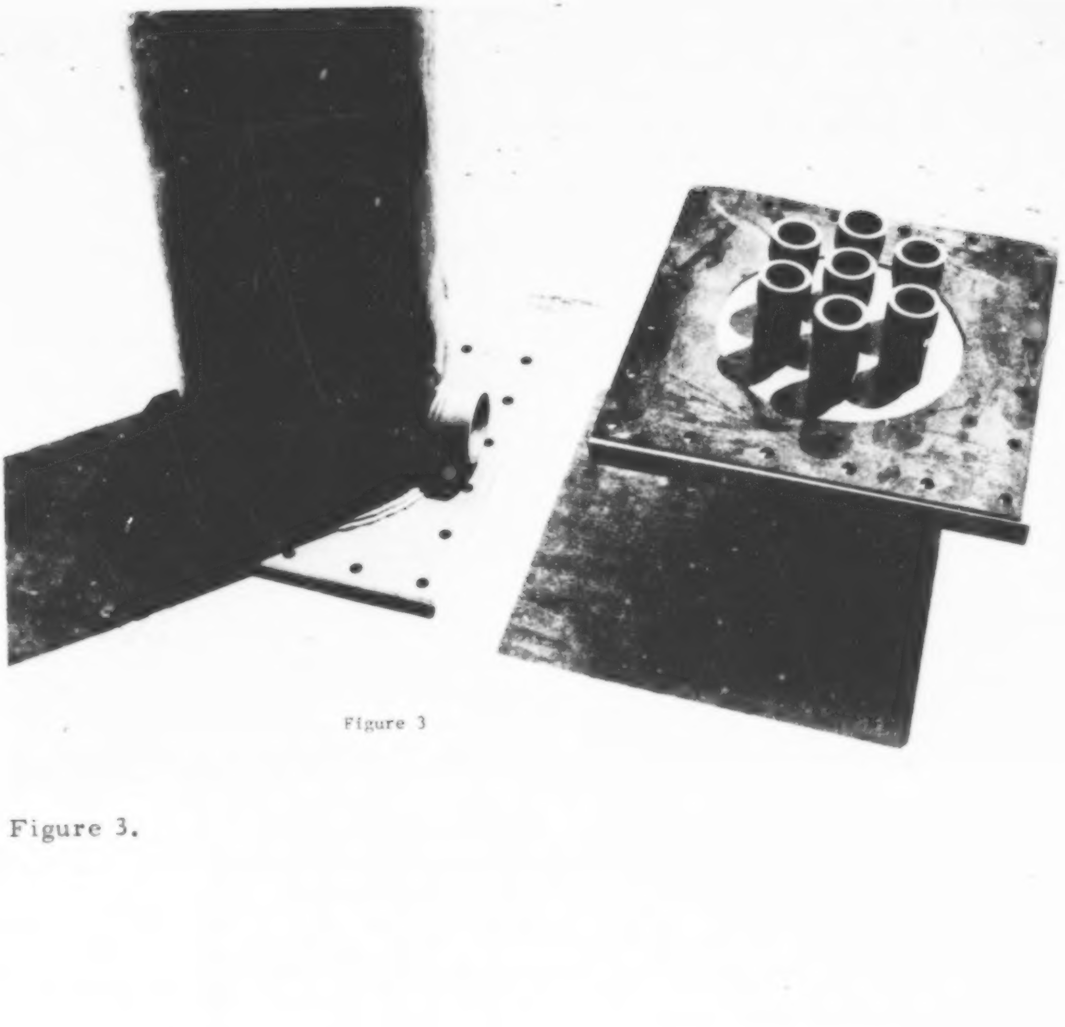

Figure 3

Figure 3.

Zeolite water softening is exchange of hardness cations, calcium and magnesium, from the water for sodium on the ion exchange resin.

$$2RNa + Ca\,(HCO_3)_2 \leftrightharpoons R_2\,Ca + Na_2CO_3 + CO_2 + H_2O$$

$$2RNa + Mg\,Cl_2 \leftrightharpoons R_2Mg + 2NaCl$$

I, for one, see no substantial advantage in such an operation except for boiler feed, and for a number of reasons would oppose its application on a municipal scale. Nevertheless, the general public has been sold on the idea of soft water, pretty much as it has been sold on other harmful products, and the result is a massive discharge of high concentrations of sodium chloride during the regeneration of the exchanger.

$$R_2Ca + R_2Mg + 4NaCl \rightleftharpoons 4RNa + CaCl_2 + MgCl_2$$

Because the usually employed sulfonic cation exchange resin has a much higher affinity for the divalent than for the monovalent ions, a considerable excess of salt is usually, if quite unnecessarily, used to convert the exchanger to the usable sodium form. The regenerant effluent thus is a fairly concentrated solution of sodium chloride contaminated with calcium and magnesium, of no use to anybody and a troublemaker.

A quick think-back to high school chemistry teaches us that addition of sodium carbonate to the spent regenerant will precipitate calcium carbonate.

$$CaCl_2 + Na_2CO_3 \longrightarrow CaCO_3 + 2NaCl$$

Calcium carbonate settles very easily and if one wanted to filter, would filter with no trouble. However, when the effluent is made alkaline, we also get magnesium hydroxide, a substance known to everybody from his prep. chemistry course as that doggone goo that won't filter. It also does not want to settle, an illustration being the extremely large settling tanks involved in production of magnesium hydroxide from sea water.

Now, everybody knows that the way to handle magnesium hydroxide is to settle it out, just as everybody knows that a primary settler is a fairly big and expensive, and sometimes evil smelling, tank.

The problem is that a small operator, say a relatively small canner or freezer who softens his boiler feed, and, possibly, final wash water, or a small town soft drink bottler, does not want to tie up his money and valuable space in a settling tank just because some government official tells him that he must not ruin everybody else's drinking water. Yet he may well want to reuse his spent regenerant, if only he did not have to make that investment.

So back to the settling tank. Settling tank size and thus cost is a function of solids settling rate and concentration. That is, it takes a given time to settle out a given amount of a suspended solid of a certain settling rate without it making much of a difference, up to a certain compaction point, how concentrated the suspension is.

Thus, it can be reasoned that were one to build a tank with canvas walls, the solution would go out through the fabric and the required holding capacity would diminish. This in turn leads to the concept of a very narrow and tall tank and to our way of thinking the logical outcome is the unit shown in Figure 4.

The regenerant effluent to which we added sodium carbonate is pumped to the top distributor of the unit. From there the slurry flows down through the hoses and the clear filtrate permeates through the fabric. The fabric is cotton tubing manufactured by the Tape-Craft Company in Anniston, Ala., and sold as "Soaker Hose." It is normally used for slow irrigation in gardening. The permeate collects in the filtrate collector and flows out through the outlet. The compacted sludge collects in the discharge cone from which it is intermittently removed by opening a valve. Instead of a valve, one really should have some continuous removal device, such as a screw, a Moyno pump, or some other rate-programed gadget.

Figure 5 is a close-up of the Uni-Flow filter bottom. The white material in the cone is a mixture of calcium carbonate and magnesium hydroxide and the clear stream is a solution of sodium chloride. This sodium chloride, rather than going to the sewer, can go back to regeneration and save money.

That savings may be able to persuade the processor to stop discharging his pollutant.

The principal reject material of the wine industry is wine lees. This is the material left in the tank after the wine is drawn off. Lees have a common feature with magnesium hydroxide. They are a gooey mess that does not want to filter. Yet they are found in the bottom of the tank; ergo, they settled out.

We pumped them up and let them run through the Uni-Flow filter and collected the filtrate at a rate of 7 gallons per minute. The filter had 7 hoses 14 feet long. The rate was thus, as near as makes no difference, 0.3 gpm/sq. ft. of hose. I built a similar filter that handles 50 gpm of lees for about $800. If you wish to operate the unit 3 months out of the year, you find the following fixed charges:

Depreciation 10 years	$80.00
Capital cost 7% p.a.	56.00
Maintenance 3% p.a.	24.00
Hose replacement in 16 months at 4 cents per ft. of hose	3.25
At 22 days per month = 1,572,000 gallons	$163.25
Per 1000 gallons	1¢

The recovery of 1000 gallons of wine worth at least $500 will thus require an expenditure of 1 cent in facilities. I did not include a pump since a winery has plenty of idle pumps during that period in which it wishes to process lees.

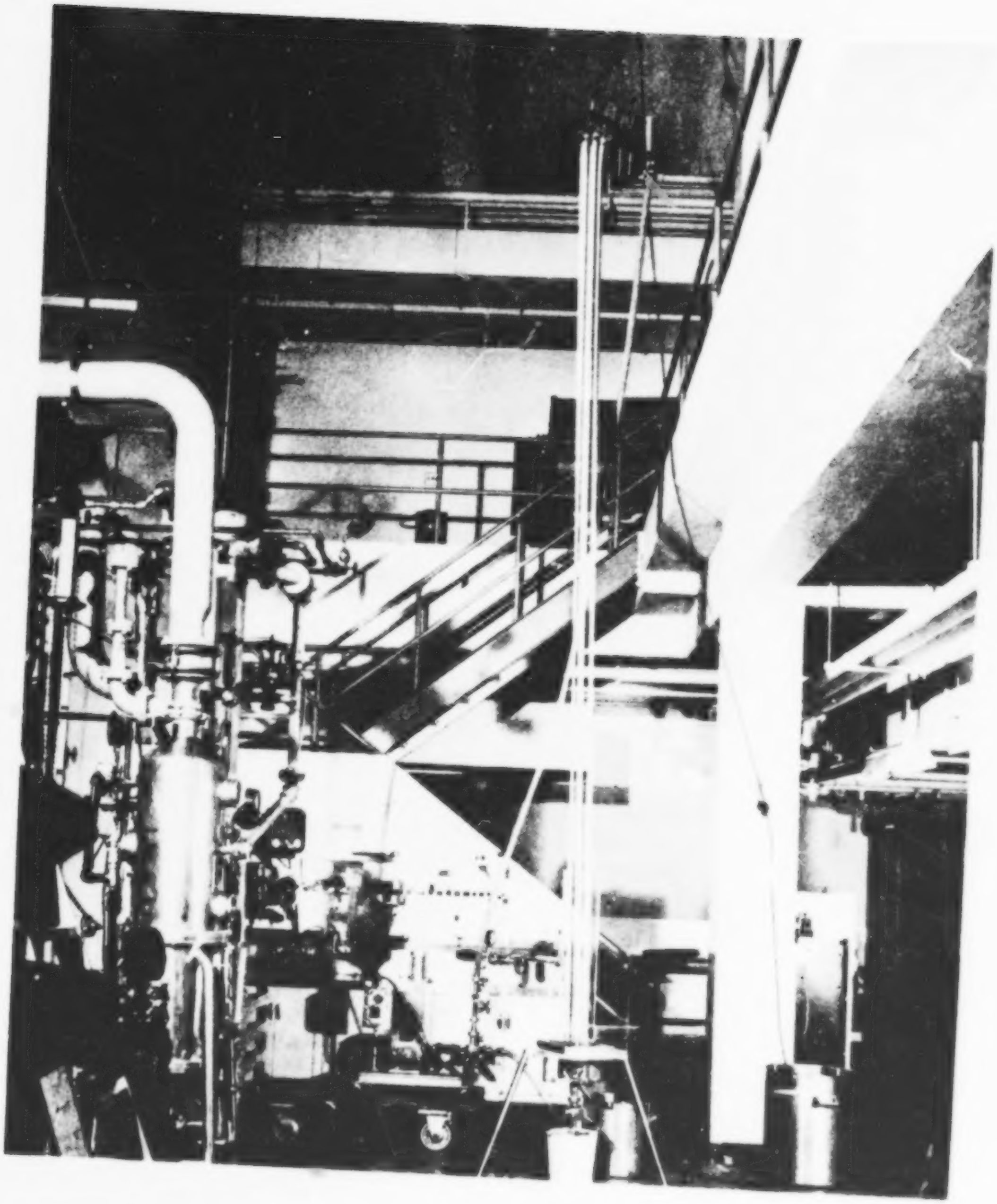

Figure 4.

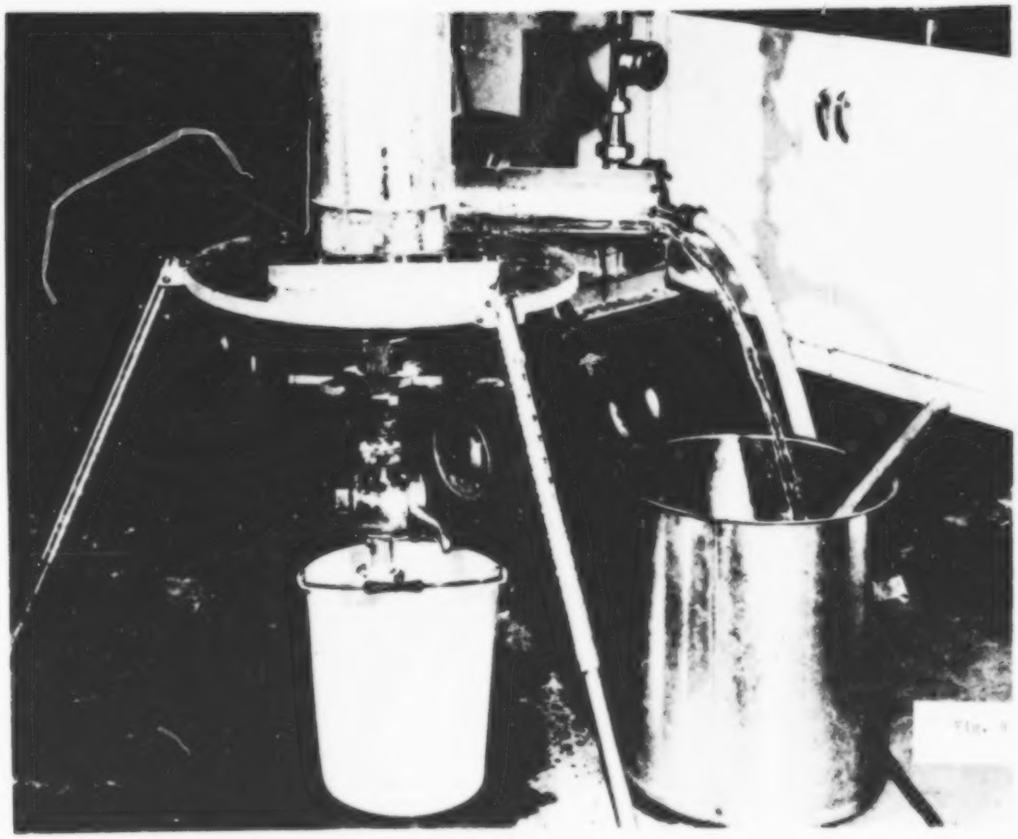

Figure 5.

Figures 6, 7, 8 and 9 show the results. Note the exponential type of settling.

While on the subject of wine, I would like to say that the Uni-Flow filter is an intrinsic part of a still slops disposal process that we developed. Still slops are an extremely noxious pollutant and the Uni-Flow filter does what some would have a centrifuge do by way of solids separation. To differ from a centrifuge, it does it at a lower order of magnitude cost.

Figure 10 shows the filtrate with a subsequent cold throw of saleable potassium bitartrate. The tartrate value pays for processing and gives a profit. Here again we have a situation I like to see.

It is too early and always will be too early to enumerate all that the Uni-Flow filter can do to alleviate pollution. We have looked so far at potato starch, where we had very encouraging results on cold cut starch waters - the elimination of suspended solids was around 98%, with no problems. With blanching waters, however, we had some clogging. Preliminary experimental work with nylon, rather than cotton, was encouraging enough to make us think in terms of non-wetting fiber tubes for some of the more difficult to handle materials, such as cane juice or tomato juice.

We tried to eliminate clay from flume waters and were successful, and we are toying with the idea of algae skim-off and compaction. We also installed a unit at a local sewer plant and found a reduction of 92% of the suspended solids of raw sewage after the comminutor.

Laboratory experiments teach us that better than 99% can be obtained after very low liming.

No doubt we will find things we cannot handle; so far we have found only very few and none of them related to the topic of this meeting.

One thus would be likely to want to think in terms of re-use of handling waters, of elimination of fiber in pineapple waste, concentration of suspensions from stick water, and such like.

Ending, as I should, on an optimistic note, I say: Eureka, we have a poor man's centrifuge!

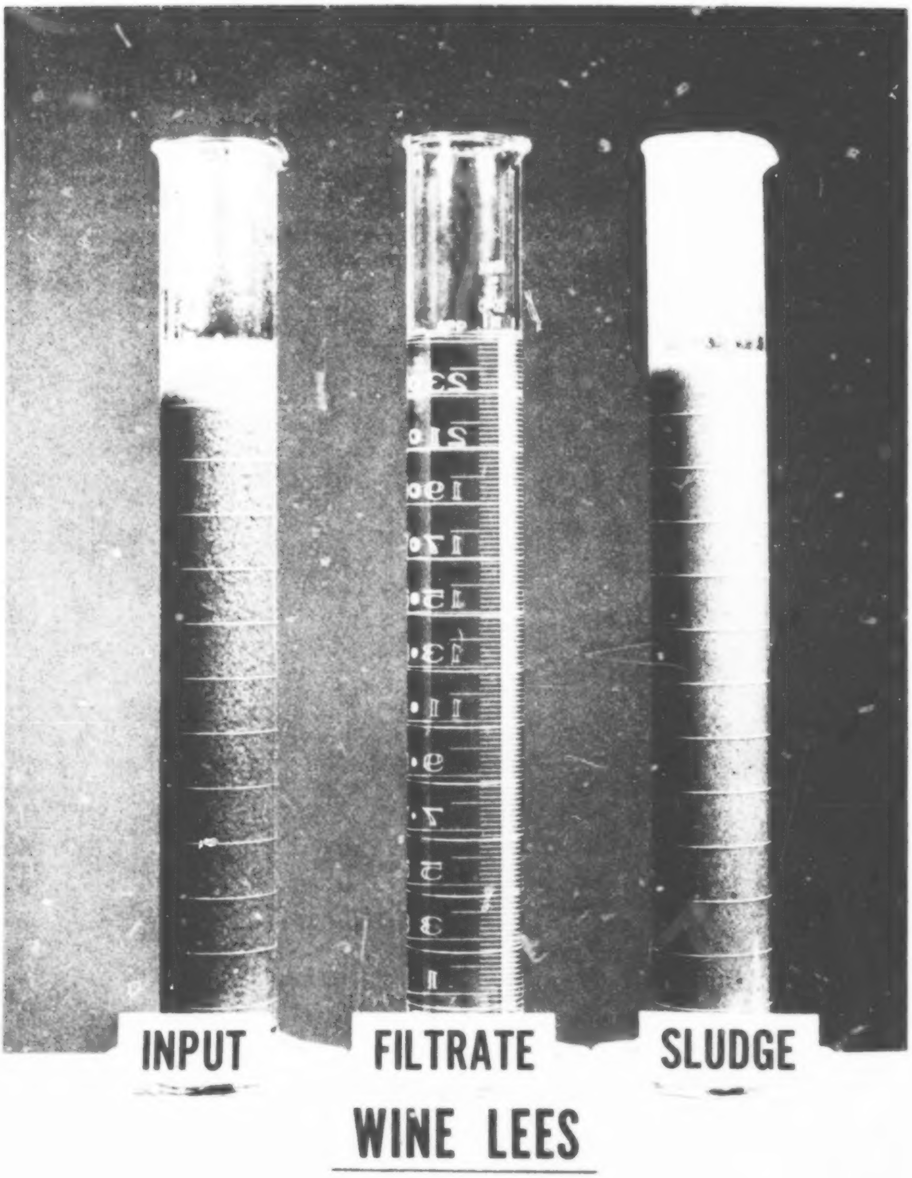
INPUT
FILTRATE
SLUDGE
WINE LEES

Figure 6.

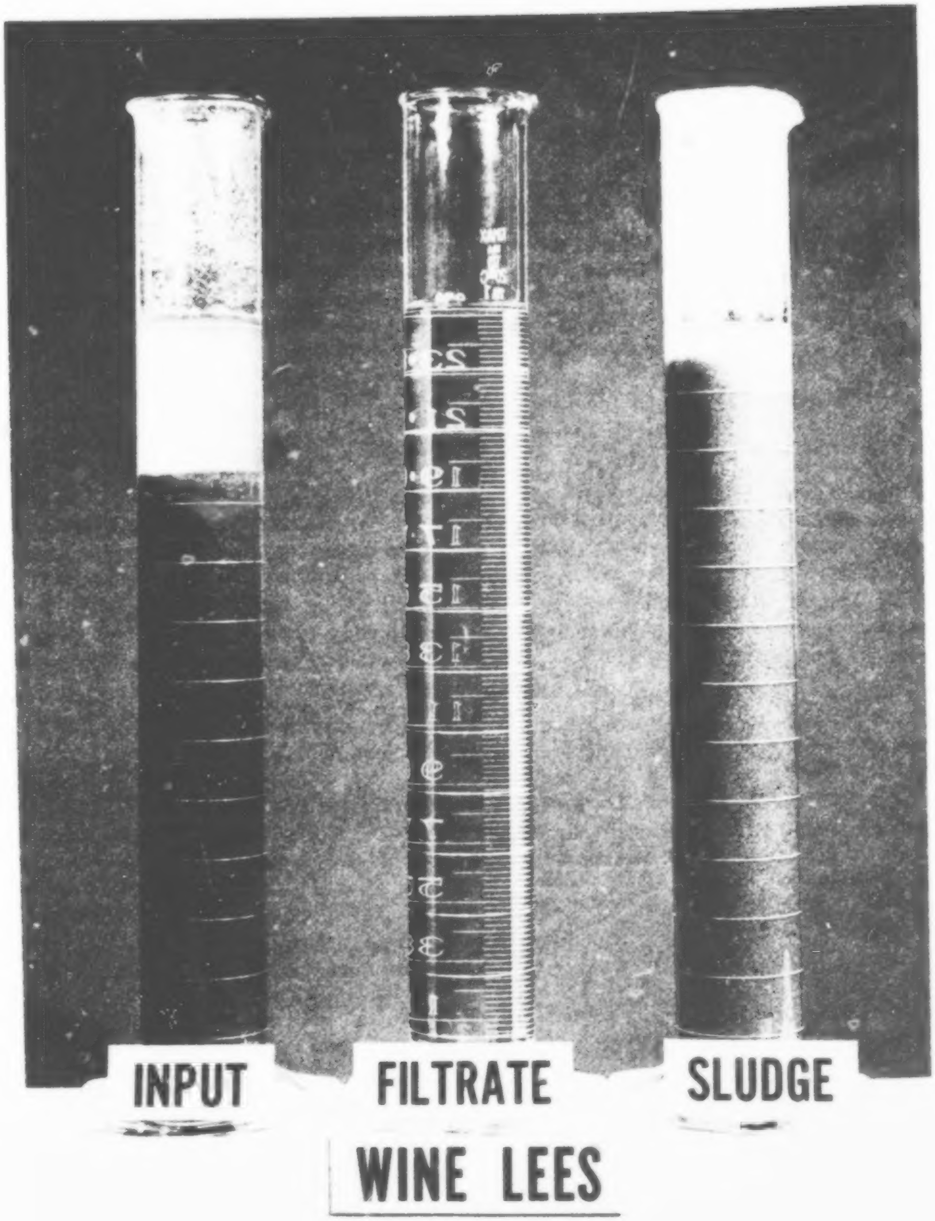
INPUT
FILTRATE
SLUDGE
WINE LEES

Figure 7.

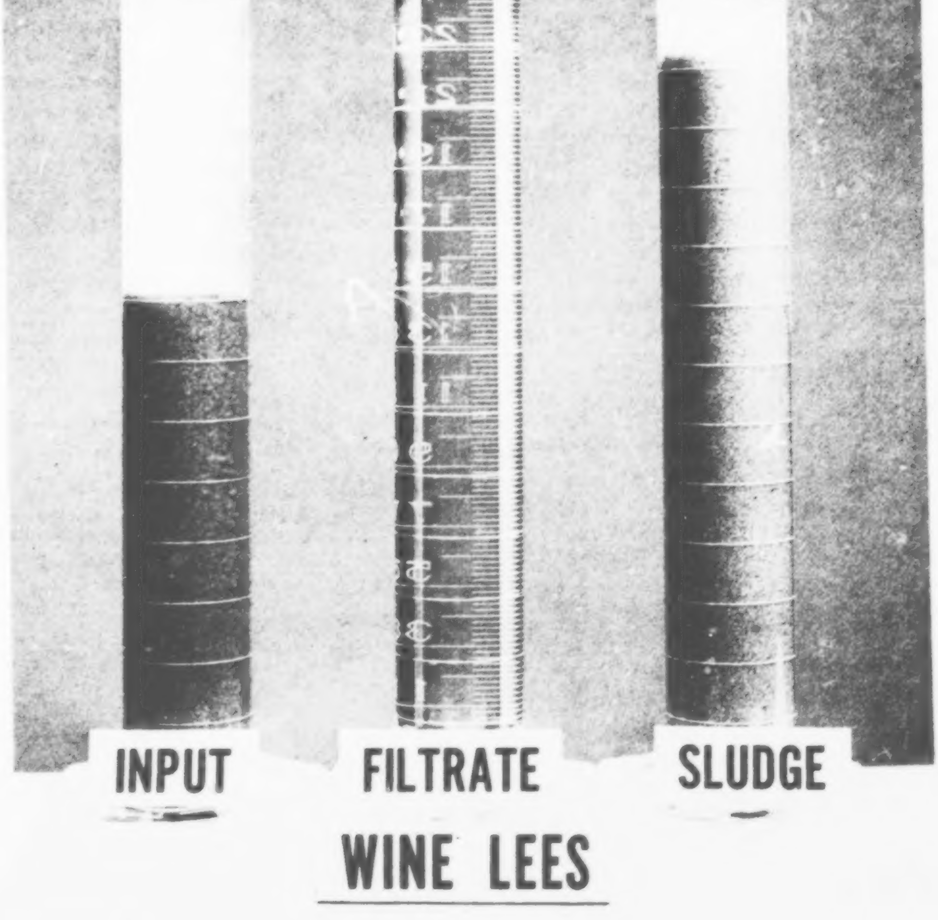
INPUT
FILTRATE
SLUDGE
WINE LEES

Figure 8.

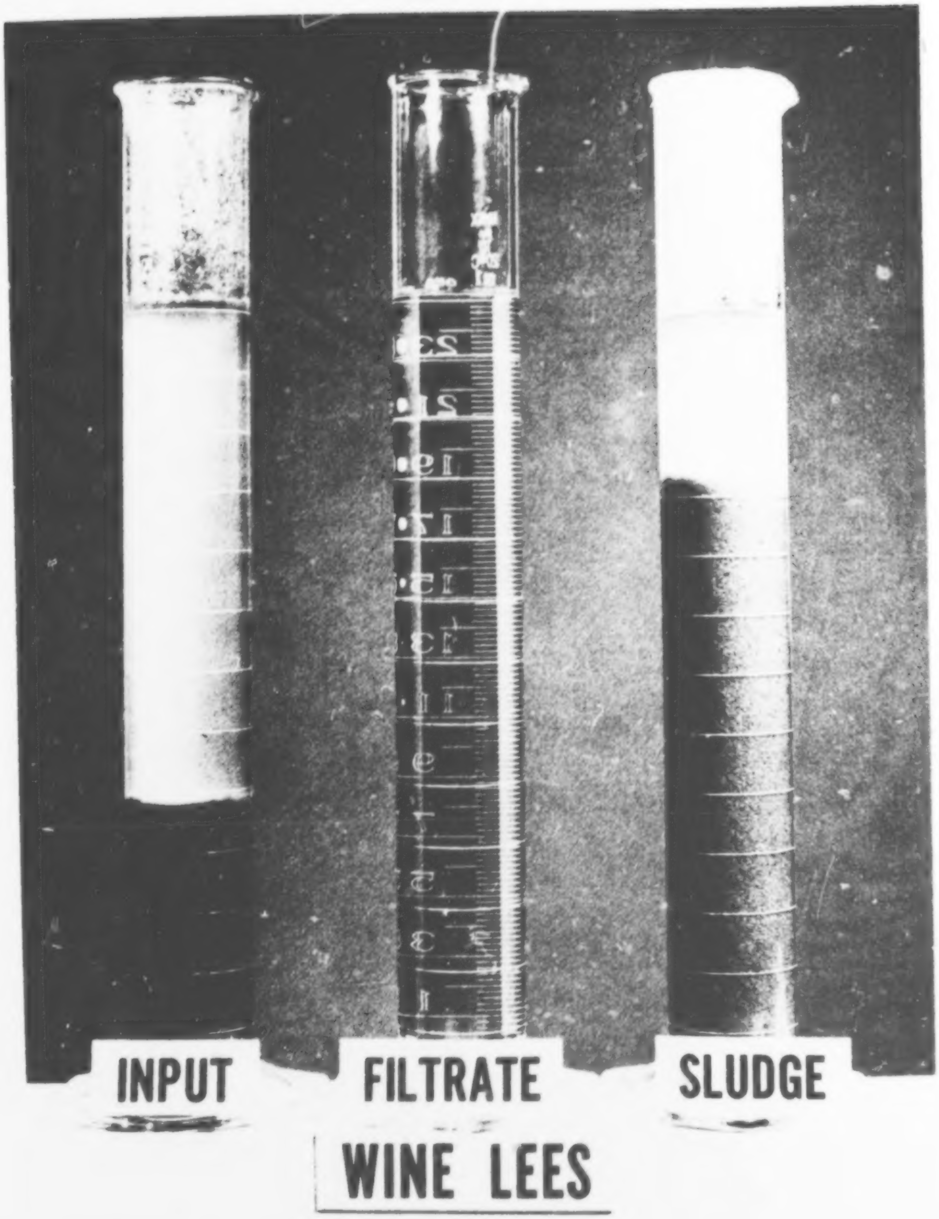
INPUT
FILTRATE
SLUDGE
WINE LEES

Figure 9.

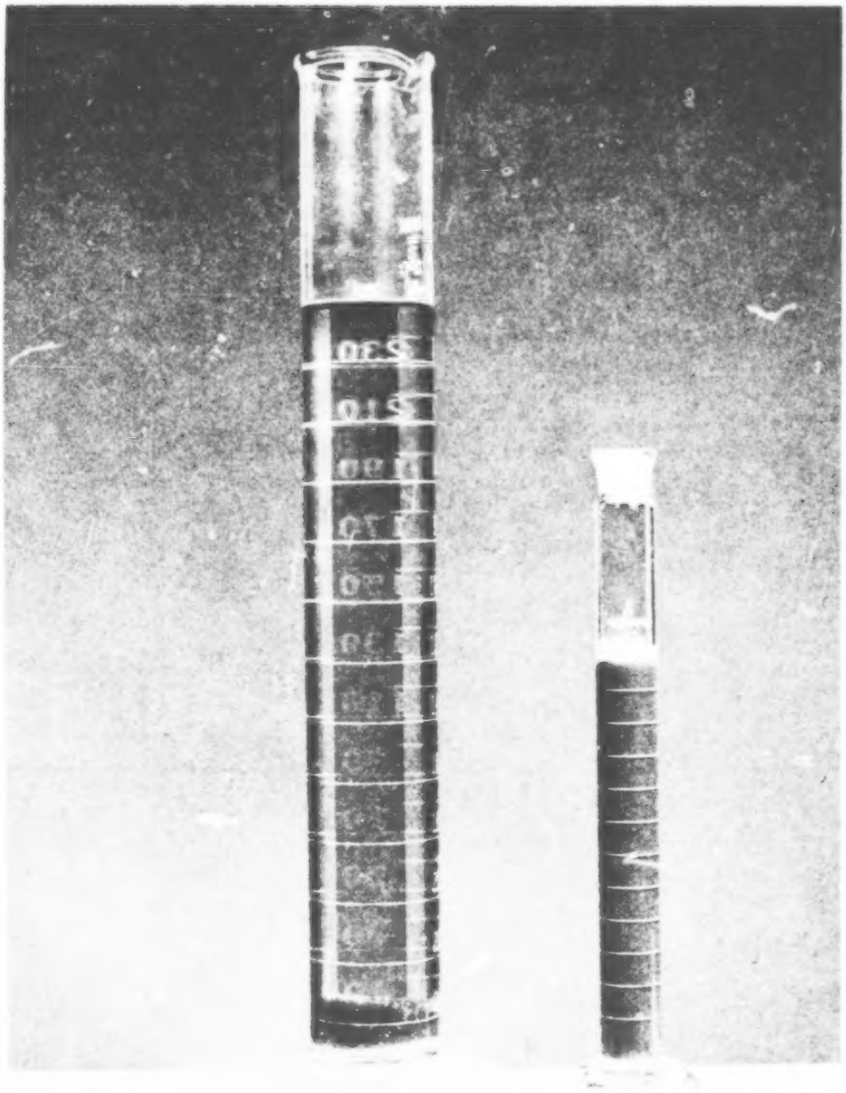
FILTRATE
AFTER COOLING
SLUDGE

Figure 10.

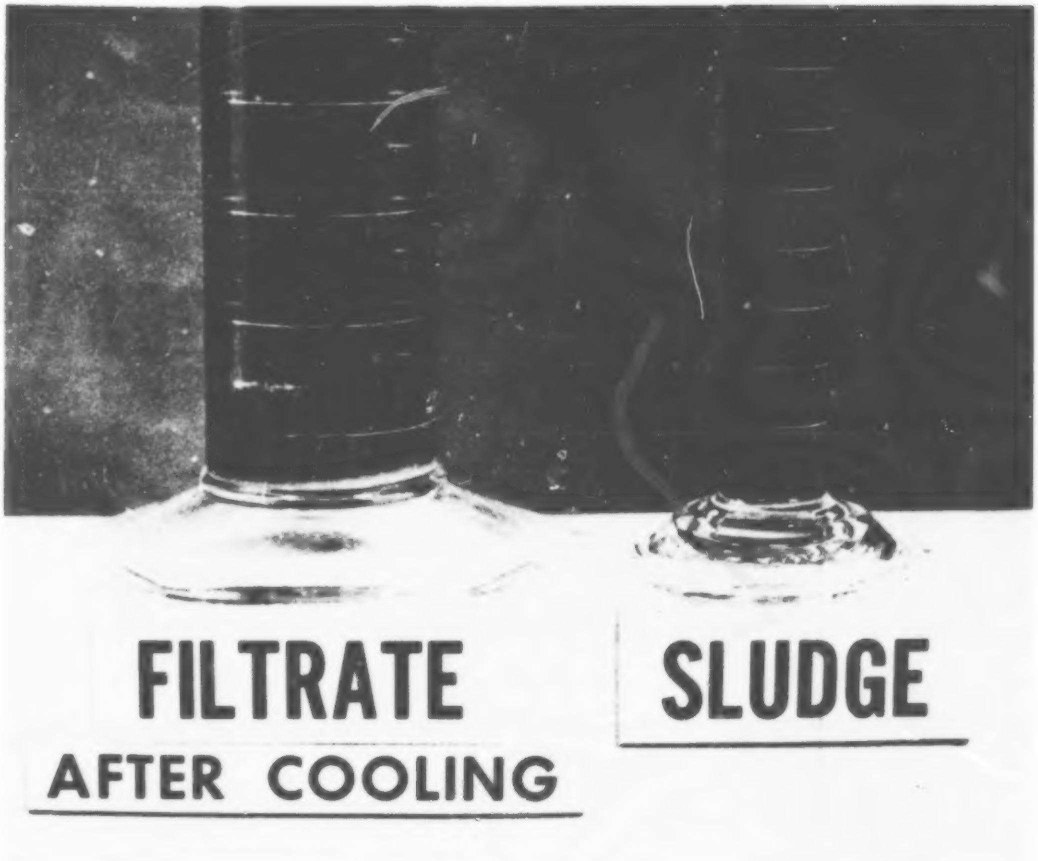
FILTRATE
AFTER COOLING
SLUDGE

Figure 11.

A CASE HISTORY IN FOOD PLANT WASTE WATER CONSERVATION AND PRETREATMENT EXPERIENCE

by

Granville Perkins[1]

Artichoke Industries, Inc. is a grower-shipper owned specialty food processor of frozen and canned artichoke products. The plant is located in Castroville, California, an unincorporated town of 3800 population in the hear of the artichoke growing area on Monterey Bay.

The town and 10,000 acres of artichokes occupy the mouth of the Salinas Valley in Monterey County. The acreage is served by four fresh shippers and two processors specializing in this commodity. The two processors perform a market support function for the fresh shippers by absorbing small sized marketable artichokes to be converted into artichoke hearts and canned in glass with vegetable oil and spice as marinated artichoke hearts, or packed as frozen hearts in retail packages.

Large unmarketable artichokes are prepared to recover the bottoms of the artichokes that are processed in glass with brine, oil or tomato cocktail sauce or fresh frozen in institutional packages for restaurant use.

In the fall of 1955 Artichoke Industries, Inc. started operations in a 40 x 200 foot metal building. That first year the plant processed 1,350,000 pounds of raw product over a seven month period. The preparation system developed for processing artichokes, a difficult, highly oxidizable product, depended upon water driven cutting equipment called hydroughts. Cone shaped knives rotating at high speed shaved the stem end of the artichoke until all of the stem and 3/4 of the leaves were cut from the heart. The water used for driving the cutters was exhausted in a flume and carried away the waste portions of the artichoke. The resulting slurry of artichoke parts and shavings was transported by flumes and gutters to a dewatering belt which separated most of the waste from the water. The waste was hauled away and fed on the ground as cattle feed. The water was discharged into a small sump and from there to the sewer.

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[1] Artichoke Industries, Inc., Castroville, California.

The community of Castroville is served by the Castroville County Sanitation District. This district defines the city limits of the town and receives all domestic and industrial waste from this community and treats it in a common two stage municipal treatment plant, designed principally for domestic waste treatment. The plant consists of a primary clarifier, bio filter, aeration tanks, secondary clarifier, and sludge digester. The effluent from the plant discharges into a slough known as the Tembladero, and from there, with the help of irrigation tail water and rain water runoff, to Moss Landing Harbor and Monterey Bay.

The average design capacity of this system is 300,000 gallons per day, hydraulic capacity for peak flows, 900,000 gallons per day, and a design population equivalent of 3000. In 1955 the population of the town was 1900.

Visits to our plant by Sanitation District representatives started in 1955 when the flow from Artichoke Industries was probably 100,000 gallons of water per day. The flow increased to 200,000 gallons in 1956 and so did the frequency of visits from the Sanitation District. In 1957 the flow had increased to about 300,000 gallons per day. The BOD was not too high but the hydraulic load on the Sanitation District by all contributors was about 3 times what they could handle in a satisfactory manner.

In 1957 mechanical trimming machines not driven by water were replacing the water-driven hydroughts. The business was growing and the logical use of water for pumping and handling of the highly oxidizable artichoke hearts was growing at nearly the same rate. The mechanical trimmers helped to reduce the load but fluming with all fresh water was still in general practice.

In 1958 we reached the peak of our water usage of over 400,000 gallons per operating day. The artichoke tonnage had increased 7 times and the waste water volume had increased 4 times over a period of 4 years. You can imagine the concern of the operators of our District Treatment Plant when over a period of four years the hydraulic volume went from 250,000 gallons per day to over 1,000,000 gallons per day, all because of two small processing plants. They were constantly in trouble. They had talked to us many times over this period about reducing our hydraulic load. We listened, but we had more important problems.

Then one day they caught our attention. We were told that if we did not take substantial measures to reduce our hydraulic load to the sewage treatment plant, they would fill our sewer line full of concrete.

We decided not to test this threat and if you can't whip them the next best bet is to join them. We visited the treatment plant, not once, but often. We learned how it was operated and learned about their problems.

This started the long, hard road back to sensible utilization of our important resources--water and the tax dollar.

The first effort was water re-use. A lot of time and effort went into pumping water from one use to another. Over a period of one year, we reduced our daily usage from over 400,000 gallons to about 300,000 gallons.

Then we received a shock. Our BOD had gone from 1500 ppm to 4000 ppm. Originally, we had short time contact between waste and water. With the re-circulation technique fully developed, we used water as many as nine times for gutter flushing as a final use before discharging. We had concentrated soluble solids by re-circulating, even though the water was continually screened before each use. The period of 1959 to 1960 can be called the "re-circulating era".

Then came the "screw conveyor and pneumatic era," 1961 to 1963. We jack-hammered the bottom out of our floor gutters and placed steel shells and screw conveyors in our gutters, back pumping the shells with concrete.

We used a variety of slingers and blowers, winding up with a Buffalo Forge 10" cast iron shell with our own design armor plate impellor. We used 10" well casing for blow pipe. Blowers cut down on water, but they do not accommodate metallic objects. We were constantly patching up holes caused by misplaced wrenches and screwdrivers. In 1963 operating officials of our Sanitation District developed an ordinance which when passed by the County Board of Supervisors created the Castroville Public Works Advisory Committee to the Board of Supervisors. I was invited by our district supervisor to be a member of this Advisory Committee. I jumped at the chance. The Committee held public meetings and advised the Public Service Division of the County Road Department on matters affecting the various service districts they had charge of for the community of Castroville. The Sanitation District was one of these.

In 1964 the Advisory Committee started a study on an Industrial Sewage Ordinance. The Ordinance limited the gallons per industry per day and established the pounds of BOD per day. Based on a formula including assessed valuation and payroll, additional amounts of BOD could be purchased from the District if treatment plant capacity was available. There is a free base allowance of treatment capacity with additional treatment capacity for a fee, if available. It is not considered a fine for exceeding your allotment.

The Ordinance controls the types of things that are not discharged, limits ether soluble materials, BOD, and suspended solids, and it requires daily meter records and reports from an independent laboratory at regular intervals concerning limiting factors. Our plant base limit is 60,000 gallons per day at 500 ppm BOD, which converts to 240 pounds of BOD per day at no fee.

In 1964, while the Advisory Board was studying an ordinance, Artichoke Industries employed a consulting engineering firm to study pre-treatment. After several months of study and design, a chemical precipitation system preceeded by a 60,000 gallon receiving and mixing tank was recommended by the consultant. A centrifuge was to be used to concentrate the sludge. We started building our treatment plant in 1965 following the consultant's design recommendation. We had decided that we had to reduce capacity of a pre-treatment system to 60,000 gallons in order to fit the system into the space available and to reduce the pre-treatment cost to something that would not put us out of business. We had decided by this time that we had better not get the product or its waste wet, if we could possibly help it. Once you decide this, lots of ideas occur that help reduce the use of water.

Again, an inventory of water uses was taken. As a result, spray nozzle sizes were reduced for wetting product with a fog in order to reduce the oxidation, rather than literally flooding it with fan sprays, and pneumatic separators replaced rod reel washers. Trimming machines were re-designed to incorporate pneumatic separation at the point of cutting. At every step, where possible, waste was separated from product and handled dry. Product cooling water for the freezer line is re-circulated, screened, refrigerated, and used over and over. A low pH citric acid solution minimizes bacterial buildup at the 50°F temperature. Blancher make-up is held to an absolute minimum. Blancher water is the highest BOD water in our plant and highly respected as such.

Jar washing serves a dual purpose. The temperature is 165°F and the water contains non-foaming detergent. This hot water is used as a pre-sterilizing tempering wash and is constantly recirculated to serve as the first stage in cooling. The balance of the jar cooling is accomplished by a combination of fog nozzles and air to make use of the latent heat of evaporation.

In 1965 the Advisory Committee recommended that an improvement tax be levied on property to pay for an addition to the District Sewage Treatment Plant. This tax was figured in the budget for 1966. When the property owners received the increase in their tax bills, they were ready to run the Advisory Committee out of town.

By 1966, the District Treatment Plant addition was under construction. Artichoke Industries had brought waste water usage down to 150,000 gallons of water per day with an average BOD of 840 ppm. The raw material handled over an eleven-month period had increased better than 10 times since 1956, and we were using 50,000 gallons less water than in 1956.

In 1967 our own pre-treatment plant began operation. It was designed for 100 gallons per minute, or our quota of 60,000 gallons to be run in 10 hours of daytime operation. It did not work out that way. At 45 gallons per minute, we had 5-day BOD of 460 ppm, suspended solids 20 ppm, BOD reduction of 75 per cent at a 50 per cent of design flow.

After a year of practicing the art of precipitation, we were able to obtain BOD of 700 ppm with suspended solids of about 25 to 35 ppm, at 85 gallons per minute. The cost of operation was fantastic in labor and chemicals. We could not operate the above-noted levels at normal plant waste water flow and ran the pre-treatment only during the day so we could watch it.

After one year of pre-treatment, we had our daily volume down to 80,000 gallons by constant attention to plant water usage reductions.

BOD was still bouncing from 600 to 1000 ppm, depending on how we loaded our plant. Our percentage of BOD reduction was, at best, 60 per cent. Because of the precipitation chemicals, our effluent went from 5.5 pH, because of acid blanching that our product requires, to a pH of 10-11.

It is now 1968. The District Sewage Treatment addition, consisting of a large mixing basin, additional secondary clarifier and additional sludge digester, giving the municipal system 800,000 gallons per day added capacity, is completed. We are gradually cutting down on our processing plant water requirements. We have, by late 1968, reduced our hydraulic load to 40,000 gallons per day.

As we reduced our daily gallonage from 80,000 to 40,000, something else happened. We began concentrating our soluble solids. By pre-treatment, we were removing good percentages of ether soluble materials from our oil packaging operations and doing a good job on suspended solids. With no oxidation or secondary treatment, we had reached the end of the line with soluble solids.

The area we have for pre-treatment measures 50 feet by 80 feet. This certainly limits how much you can expect to do. It is surprising how much money you can spend in 4000 square feet.

By the end of May, 1969, we thought we had turned ourselves inside out. We were not happy with our expensive precipitator, but it was reducing BOD by 50 to 60 percent. We were then told that our high pH discharge was causing problems at the District Treatment Plant. Something was causing their clarifiers not to work. Their suspended solids were remaining suspended to a high degree. After several days of experimentation, we shut down our precipitator and just allowed the waste water to flow through with no chemicals added. Within a few days, the District suspended solids problem cleared up at the sewage treatment plant. Our BOD jumped from an average 800 ppm to 1200 ppm. We accomplished nearly a one-third reduction in BOD by just running our plant discharge through the precipitator tank. The processing plant discharge was about 2,000 ppm BOD.

Disappointed in cost and results with the first consultant's design, we hired another. The chemical engineer we employed analyzed data based on a 24-hour sampling of our plant discharge. He came to the conclusion that, due to the specific gravity of our suspended solids, we could more efficiently float them than precipitate them. We agreed with his analysis.

We are now in the process of converting a 6,000 gallon precipitator into an 8,000 gallon clarifier by reversing the flow and making some modifications. We intend to make additional modifications to create a flotation unit.

We are continually analyzing our processes to reduce water usage and reduce water contamination.

At present, we are separating our water by quality and plan to handle these separately. Why run 50 ppm BOD water through pre-treatment when it can be blended with post pre-treatment effluent ahead of the meter? In our particular case we take the hydraulic load off the treatment plant and dilute the BOD of the pre-treated effluent before discharge.

We know there are many things left to do in the processing plant and in the pre-treatment area. This project will be with us as long as we are there. We have accepted waste water handling as an extension of our manufacturing process.

With all the trials and tribulations, we believe this story is worth telling. It shows what can be done when it has to be done. If there is something to be learned from our mistakes, they are submitted to you along with our accomplishments.

ANIMAL FEEDS FROM VEGETABLE WASTES

by

George O. Kohler[1]

My objective this afternoon is to present to you a progress report on two agricultural waste problems which are causing serious environmental pollution problems in agricultural areas. These wastes are lignified cellulosic materials such as straws, oilseed hulls, corncobs, etc., and the non-edible green wastes from truck farms.

More than 150 million tons of cellulosic agricultural wastes are produced annually in the United States. This figure does not include sawdust, which amounts to 40 million tons, or animal wastes, which contain another 150 million tons of solids. Commercial production of vegetables contributes an additional more than 300 million tons of fresh waste annually.

Cereal straws constitute the largest single source of wastes which up until now represent a relatively neglected agricultural resource. To orient the problem more regionally, about 1 to 2 million tons of rice straw grown in the Central Valley of California go to waste and a similar quantity of perennial grass straw grown in the Pacific Northwest is also wasted. Traditionally it has been cheaper to burn these straws after harvesting the seed than to utilize them in any other way. However, recent anti-air-pollution legislation makes it imperative to develop alternative disposal procedures and we have been working along these lines for some time. Simple ploughing back into the soil is impossible with the perennial grass crops and is considered unsound and uneconomical by most rice farmers.

Most of the discussions we have had during the past several days of this conference have been directed toward getting rid of pollutants after they have been generated by developing new or improved process steps. For some types of pollution these are undoubtedly the most logical approaches. My interest is in converting waste materials into feeds. As a neo-Malthusian I believe we will need greater food supplies before the population density is stabilized. Even today some agricultural wastes have the potential of providing cheaper feeds than crops grown primarily for that purpose. For the past eight years we have been carrying out research on lignified cellulosic wastes or byproducts, including alfalfa stems, wheat straw and corn cobs, in cooperation with the Nebraska Experiment Station; on grass straw from seed production in cooperation with Oregon State University; and on rice straw in cooperation with the University of California at Davis. Ruminants and other herbivorous animals are uniquely adapted to digest the cell wall constituents in these fibrous wastes. But lignin, an indigestible substance, is associated with the cell wall cellulose and hemicellulose and tends to decrease their digestibility. The partial crystallinity of cellulose itself may prevent complete digestion of high fiber feeds.

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Research has shown that processing straws with or without chemicals can modify both lignin and cellulose and increase overall digestibility. This is important because we know from experience that animals cannot physically consume enough low digestibility feed to maintain themselves adequately. For example, unprocessed rice straw is a poor substitute for dehydrated alfalfa because it contains too little energy as well as too little protein. However, based on our present laboratory evidence, we feel that lignified cellulosic wastes can be upgraded to the point that they can provide adequate energy for ruminant maintenance, and even for growth and/or production. Of course protein and other appropriate supplementation will be necessary to provide proper nutritional balance.

Our laboratory processing experiments have been carried out in several types of equipment. On the bench scale, we have used bombs of two different sizes made from copper or stainless tubing with standard fittings for closures. For larger scale work, we have used the pilot plant equipment at Dierks Forest, Hot Springs, Arkansas. This facility can batch process 1-1/2 cubic feet of material at steam pressures of up to 600 psig.

To test digestibility of processed materials without time consuming animal tests, we have developed an in vitro technique which uses two commercially available enzyme preparations ("Anozuka Cellulase SS" and "Pronase," a protease) to digest and solubilize the cellulosic, hemicellulosic and proteinaceous components of potential feedstuffs. This test correlates very well with standard artificial rumen studies using rumen fluid from fistulated animals, and with actual in vivo animal performance tests. A biochemical or biological evaluation of digestibility is essential because standard chemical analyses do not detect differences in digestibility of treated and untreated materials. Laboratory tests show that alkali treatment of grass straw can double the digestibility, while acid detergent fiber, crude fiber, pentosan, and lignin change very little.

All straws tested can be improved by treatment. For example, laboratory treatment of wet rice straw with 3% by weight of NaOH at 231° for 3 minutes almost doubles the apparent digestibility; corresponding treatment of barley straw increases apparent digestibility by 120%. We are presently carrying out intensive laboratory investigations of the effects that process variables, including alkali concentration, moisture level, temperature, and reaction time, have on the digestibility of rice straw. Promising treatments are already being expanded to the pilot plant scale and enough materials will be prepared for large animal feeding trials at Davis.

A variety of lignified cellulosic wastes like sugar cane bagasse and oil seed hulls accumulate at processing plants. Since no additional transportation costs are required to make these materials available for treatment, they represent a prime source of potential feedstuffs. Laboratory data show that excellent apparent digestibility increases can be achieved by processing them with alkali. Even manure digestibility is greatly improved by alkali treatment. Feed potential of these materials looks considerably brighter than that of sawdust, probably because the vegetable products have a relatively lower lignin content initially.

Turning now to the second waste problem, waste materials from green vegetables, in the relatively small Salinas valley of California, about 60,000 tons of cauliflower waste are produced annually. Production is spread out over 10 months so that some material is available throughout most of the year. Presently, following removal of the blossoms for the fresh vegetable market, the fresh cauliflower leaves and stems are trucked back to the fields from the processing sheds and dumped out on the ground. The fresh leaves decompose rapidly and so become a breeding ground for flies and create a serious odor problem. As a result of our experiences in dehydration of alfalfa, we set up a cooperative project with a commercial firm to try to solve this particular agricultural waste problem in a way that might profit both the farmer and the processor.

Whole cauliflower plants were obtained from two fields near Salinas and after removal of the blossoms, the entire plants were freeze-dried. A leaf-stem separation was then made and the respective fractions were analyzed for xanthophyll, carotene, protein, fat, fiber and ash. The analyses indicated that the very high xanthophyll and protein content of the leaf, along with a low fiber content, makes the leaf fraction look promising indeed as a poultry feed. Xanthophyll is the yellow pigment in feeds which causes skin pigmentation of broilers and the orange color of egg yolks. Likewise, the adequate protein and fiber content of the stem fraction indicates it has good potential as a cattle feed.

The limiting economic factor in the dehydration of cauliflower waste is its high moisture content. Fresh material varies from 7.5 - 10.0% solids. This, of course, means almost 100% more water has to be evaporated to obtain one pound of dehydrated cauliflower than has to be evaporated from alfalfa to obtain one pound of dehydrated material, because alfalfa has a higher initial solids content (16-24%). To circumvent this difficulty, the freshly harvested and chopped cauliflower waste was pressed by means of a sugar cane type of roll-press which we had been using in our work on wet-fractionation of alfalfa. The finely chopped cauliflower proved more difficult to press than the more fibrous alfalfa; however, by this means the solids content of the pressed cauliflower was increased to 12.0%. Thus about 30% of the water was removed with a loss of only 14% of the soluble solids.

Our next step was to make a trial run with our pilot Heil dryer. Dehydration conditions employed were similar to those used to dehydrate alfalfa and grasses. It was found that the leaf and the stem came through the drum with very different moisture contents. This differential was of benefit in carrying out the next step which was to separate the dehydrated product into leaf and stem fractions. An excellent leaf and stem separation was achieved by this means as indicated by the xanthophyll analysis for the two products. The leaf contained 191 mg/lb xanthophyll while the stem contained only 51 mg/lb.

Proximate analysis of the meals indicated that the high quality leaf meal containing up to 28% protein with a low fiber content (12.5%) should be excellent for poultry rations. In addition, the stem meal fraction for ruminant feeds was only slightly lower in protein and slightly higher in fiber. It compared very favorably with a good quality 20% protein dehydrated alfalfa meal with a 20% fiber content.

We found that pressing the chopped cauliflower prior to dehydration actually reduced the through-put time in the dehydrator by about one third. This gave a good retention of both carotene and xanthophyll in the pressed leaf fraction along with a suitable protein and fiber content for a high grade poultry feed. The corresponding stem meal from this preparation had the necessary protein and fiber content to make it an excellent cattle feed. An enzyme digestibility test run on the stem fraction indicated 86.3% digestibility, which when compared to alfalfa stem, at about 50-60% digestibility, looks promising indeed as a cattle feed.

Presently cattle feeding trials are being carried out on the stem fraction. Broiler pigmentation studies are also being conducted on a preparation of the leaf fraction to ascertain availability and potency of the xanthophylls present. These studies, combined with our work on the technique and economics of dehydrating fresh cauliflower waste, will determine the feasibility of solving a perplexing fresh-vegetable-processing pollution problem.

Economic evaluations of treated straw products and cauliflower waste products are being carried out by computer using parametric linear programming techniques.

RICE HULL UTILIZATION

by

Milton Staackmann[1]

INTRODUCTION

The disposal of rice hulls presents a major problem to the rice industry, since industrial applications for the hulls currently consume only a small fraction of the total. Nationwide, nearly a million tons of hulls are produced annually and about 20% of these originate in the Sacramento Valley area of California. Present methods of disposal include open-air burning and dumping. Such methods are becoming ever more unattractive due to air pollution in the case of burning and because of increasing hauling and landfill charges in the case of dumping.

Research activities aimed at finding potential uses for rice hulls have been going on for the past sixty years. Most of these efforts have attempted to take advantage of a single property of the hulls themselves (such as the fuel value or abrasive character) or of the ash formed by burning the hulls (as an absorbent or a ceramic raw material). In addition, much of the past work considered technical feasibility only, paying insufficient attention to economics. URS Research Company has completed a study for the US Department of Agriculture examining the technical and economic feasibility of various utilization concepts involving more than one of the properties of the hulls. The general areas examined included the following:

> Concepts making use of both the fuel value of the organic (cellulosic) portion of the hulls and the silica content;
>
> Concepts utilizing both the structural characteristics and the unique texture of the rice hulls;
>
> Concepts combining both of the above.

The most promising approaches to solution of the problem of rice hull disposal fall into two basic categories. The first category includes methods for using the heating value and the silica content of the rice hulls as elements in the manufacture of industrial products such as Portland cement, water glass, and porous silicate structural materials. The other category includes the chemical or physical bonding of rice hulls into board for architectural use. One of the most attractive approaches appears to be a manufacturing complex which converts part of the hulls into water glass which is used in the bonding of the remainder of the hulls into panel board.

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[1] URS Research Company, San Mateo, California.

CONCEPTS INVESTIGATED

Portland Cement

This concept makes use of both the heating value and silica content of the rice hulls. Hopefully, a standard Portland cement manufacturing facility could be modified to permit substituting the rice hulls for a portion of the silica supplied as a raw material and for most of the hydrocarbon fuel used in manufacture of the cement.

It appears that by merely charging the rice hulls into the rotary kiln of the plant, some difficulties may arise. During burning of the rice hulls to produce the heat necessary for chemical conversion of the various raw materials into cement, it is possible that considerable quantities of incompletely burned rice hulls could be incapsulated by the fusing materials and complete combustion of the hulls would thereby be prevented. In this manner, the total heating value of the hulls would be unavailable, and the resultant cement would be contaminated with cellulose and char. Due to this difficulty, an operable cement plant utilizing rice hulls may have to be of unconventional design, or additional equipment may be required to completely burn the hulls before entry into the kiln. Such alternative procedures are still considered to be technically feasible, since furnaces for complete combustion of rice hulls have been designed, and unconventional processing techniques such as fluidized bed reactors are used in other manufacturing processes.

The economic feasibility of using rice hulls in cement manufacture is greatly dependent upon the size of the plant being considered. It appears that new plants must have annual capacities ranging from five to ten million barrels in order to compete economically. Such a plant has very stringent requirements for the total amount of rice hulls required each year and the fraction of silica in the product cement which may be supplied by the hulls. It appears that a plant based on using the typical amounts of rice hulls available in any one geographic area would be limited in annual production of cement to two to three million barrels. The economics of production of cement utilizing rice hulls are, therefore, not favirable.

Water Glass

The production of water glass using rice hulls as a source of fuel and silica in a conventional manner could experience the same difficulties noted in the manufacture of cement. That is, significant amounts of rice hulls could be prevented from undergoing complete combustion in the process. The requirement for additional equipment for use in the conventional manufacture of water glass or for an unconventional manufacturing process is evident.

The most promising unconventional approach to manufacturing water glass would utilize the Zimmerman process (wet air oxidation). The Zimmerman process is already being successfully used in over 30 sewage disposal plants across the country and for wet oxidation of paper mill wastes, antibiotic residues, manure, etc. It appears that water glass manufacturing plants using rice hulls would be competitive in size with existing plants.

Porous Silicate Materials

This concept employs bonding the rice hull ash to form materials with a wide range of specifications. The basic idea was initiated some years ago to produce porous silica insulating refractory bricks. This product is a specialized material and requires close control of many elements of its manufacture. Whereas it appears to be a profitable process, complete penetration of the total market for this product (rather unlikely) would still provide an outlet for, at most, only a few percent of all rice hulls.

The manufacture of products with less stringent specifications appears more favorable. Such products could include the following:

Building blocks;

Architectural insulating slabs;

Pipe lagging;

Aggregate for plaster, lightweight concrete, or concrete building blocks.

Several processes for manufacture of such products have been investigated. They fall into two basic types. The first type consists of combining the hulls with a suitable fluxing agent and burning the hulls to produce the heat required to achieve bonding of the silica residue of the rice hulls. This process has the same shortcoming as the cement and water glass concepts (some hulls could be incompletely burned), but in this case the product specifications may permit it. The other process type consists of burning the hulls to produce steam and silica with subsequent use of the steam in an autoclave to bond the silica blended with fluxing agent.

The latter process, in modified form, is currently used extensively in Europe to produce calcium silicate bonded structural materials. Rice hulls have been burned to produce steam as the means of hull disposal with no attempt to recover the ash. Such boilers have become uncompetitive with conventional steam production in recent years.

In the process outlined above, the steam would be used on location and subsequent use would be made of the hulls. This process appears, therefore, to beeconomically feasible.

Board for Architectural Use

This concept makes use of the unconverted rice hulls (not the ash) bonded together to produce an architectural board with attractive textural qualities.

Processes for physically bonding the rice hulls include producing vulcanized cellulose fiber and bonding the hulls together in a matrix of sodium silicate. Difficulties in achieving high bond strength and adequate water resistance are present for these processes, but it is felt that such difficulties can be overcome by means of limited technical development programs. A number of other processes have been considered to achieve chemical bonding of the rice hulls. Such processes include bonding by means of ester or ether linkages between cellulose molecules. The primary difficulty encountered in examining these methods of bonding is excessive degradation of the cellulose.

For a successful process of this type, preliminary treatment of the hulls may be necessary to prevent such degradation. An overall system requiring pretreatment of the hulls appears to be economically unfavorable.

Combined Concept Plant

After review of the above concepts, it appears that the opportunity for combining concepts into one manufacturing complex deserves further examination. The combined plant would have two main processing areas. One area would consist of a sodium silicate manufacturing facility producing the sodium silicate using rice hulls as one of the raw materials. The output of this facility would be used in the other manufacturing area where the remainder of the rice hulls would be bonded into architectural board using sodium silicate as the binder.

Operational economy would accrue from reduction of raw material input to a few basic materials, chiefly rice hulls and sodium carbonate, as well as from the savings in packaging, shipping, and sales cost of sodium silicate that would result from its manufacture in a captive facility. In addition, this plant would be very flexible since two independently salable products would be made.

CONCLUSIONS

Investigations by URS Research Company to date have been primarily limited to paper studies of these concepts with very little laboratory work having been performed. Results which have been obtained indicate that several of the concepts are deserving of further examination. Recommended future work would resolve some of the unanswered technical problems by laboratory studies followed by pilot plant evaluations of the most deserving concepts. There is great hope that this major agricultural waste problem will be turned into a profit for the industry and will illustrate the rewards which can be achieved by application of imaginative systems engineering to pollution problems.

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